Insect and Disease Conditions in the United States ■ 1979–83

United States
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Forest Service
State and Private Forestry
Forest Pest Management

General Technical
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Foreword

In 1905, the USDA Forest Service and its first chief, Gifford Pinchot, published "The Use of the National Forest Reserves: Regulations and Instructions." Small enough for a ranger to slip into one pocket, the "Use Book" contained the essentials that an employee needed to know. Many of the philosophies expressed in the "Use Book" are still in evidence today, including the concept of protecting the forest resource.

Although Pinchot emphasized the need to protect forests from "fire, overgrazing, thieves, and reckless lumbering," he knew that insects and diseases could also devastate the resource. In that day, however, little could be done to suppress or prevent pest outbreaks. The first land managers probably viewed them as inevitable natural disasters.

Today, improved knowledge and technology make it possible for us to reduce the waste caused by insects and diseases. Much has been accomplished through the cooperative efforts of Federal, State, and private resource managers, but pest-caused losses in our forests remain unacceptably high.

This first national report on conditions over a 5-year period summarizes the status of a number of insects and diseases. Some of these pests, like the dwarf mistletoes, have long been recognized as forest management problems. The management implications of other pests, the root diseases and gypsy moth, for example, have come to our attention more recently. All of them can cause unacceptable losses. We need to take advantage of opportunities to manage these damaging pests so that our forests can better meet projected resource needs.

R. Max Peterson

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Chief

Insect and Disease Conditions in the United States 1979–83

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Introduction

This report gives a broad perspective on the status of several destructive forest pests. We have calculated the damage they caused from 1979 to 1983. Damage by some insect pests fluctuated over the 5-year period. Gypsy moth populations, for example, defoliated an unprecedented number of acres in the Northeast—and then subsided. The western spruce budworm outbreak gradually doubled in size. In contrast, outbreaks of insects such as the mountain pine beetle and spruce budworm remained relatively static. The amount of damage attributed to disease pests followed a similar pattern. Diseases, like the root diseases and dwarf mistletoes, remained at chronically damaging, but stable levels.

We have also provided information on the history of the pest, the resources affected, and the current prevention/suppression strategies.

Are we reducing pest damage?

Yes, particularly in areas where forests are being managed. Forest management largely provides both the means of and the need for practicing pest management.

Conversely, where forests are not managed, the opportunities and justification for investing in pest management are reduced. So although we have the means of reducing pest-caused losses, what we do from a practical point of view is determined by such things as economics and forest management objectives. These factors will, to a large degree, continue to determine how and where we focus our activities.

Additional information can be obtained from the Forest Pest Management offices listed in appendix 2 or from Forest Pest Management, Washington Office, P.O. Box 2417, Washington, DC 20013.

James L. Stewart
Director of Forest
Pest Management

Douglas-fir Tussock Moth

On the Downswing

Written by Leon F. Pettinger

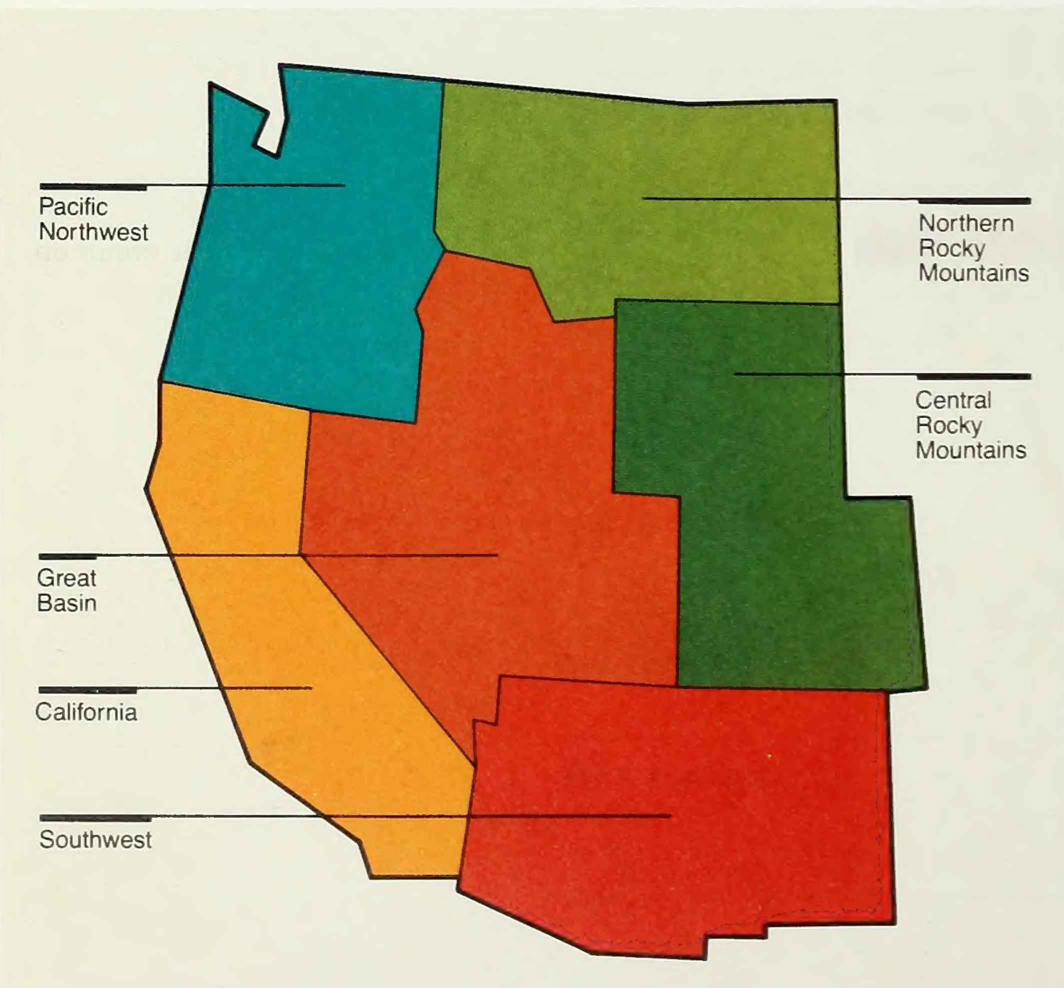
Its populations can explode. Within 1 year, a minuscule population of Douglas-fir tussock moth can grow to outbreak numbers that strip the foliage from the treetops. But when populations are low, the insect's feeding goes unnoticed, and its life stages are difficult to find.

The caterpillars, the larval stage of the tussock moth, prefer to feed on Douglas-fir, grand fir, and white fir. When grown as ornamentals, spruces, especially blue spruce, are common hosts. The tussock moth's preferred hosts vary according to location. In the Pacific Northwest and the northern Rocky Mountains, the larvae feed on Douglas-fir and grand fir. In the Great Basin, the Southwest, and California, the larvae prefer white fir. In the central Rocky Mountains, they most often damage ornamental trees, such as spruce (fig. 1).

When populations build up enough to completely defoliate their preferred hosts, the larvae will move to other trees, such as pine, larch, and spruce.

The Douglas-fir tussock moth completes its life cycle within 1 year and passes through four stages: egg, larva, pupa, and adult.

Figure 1. Range of the tussock moth. These groupings approximate the USDA Forest Service regions in the Western United States.



The larvae go through five or six stages, known as instars, growing larger with each instar. Full-grown larvae are striking caterpillars (fig. 2). In late July and August, the mature larvae spin a thin cocoon, or pupal chamber, of silken webbing mixed with body hair. About 10 to 18 days after the larvae pupate, the adult moths emerge. The wingless females cannot fly. Attached to their cocoons, they emit a chemical messenger, called a pheromone, to attract the males (fig. 3). After they mate, the females lay eggs, and the pattern repeats itself (fig. 4).

From 1979 to 1983, outbreaks were relatively small. In effect, the moth "disappeared" for 5 years.

Historical Perspective

Outbreaks have occurred many times since recordkeeping began early in this century. Populations tend to increase at 7- to 9-year intervals. Figure 5 displays the historical record of outbreaks from the 1920's to 1983. Shown are only those outbreaks that caused visible defoliation, that is, defoliation mapped in aerial surveys.

The most common type of outbreak sequence is also the most impressive, involving thousands of acres of host type. These outbreaks are characterized by a rapid population buildup, possibly severe defoliation, and rapid—almost total—population collapse.

This outbreak cycle has a definite pattern of four phases. Each phase will generally last 1 year (Wickman and others 1973)

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Figure 2. **Full-grown Douglas-fir tussock moth larva, about 1½ inch (35 mm) long.**

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Figure 3. **Female moths attached to their cocoons. One female has already laid four white eggs.**

F-705627

Figure 4. **Larvae dispersing from egg.**

(fig. 6). During Phase I, the population increases rapidly to outbreak levels; defoliation, however, is generally spotty and light. Phase I is followed by Phase II, the time of maximum insect density and maximum activity. Larval numbers are highest and damage to the forest is greatest during Phase II. During Phase III, the decline phase, the population collapses rapidly. Because populations usually decline after most of the feeding has occurred, considerable defoliation can occur during this phase. If the population collapses early in the season, however, damage is correspondingly less. The final, postdecline phase is one where "harmless" remnants of the population can still be found. Defoliation is seldom seen during Phase IV. This outbreak cycle typically lasts 3 to 4 years and is the usual outbreak pattern in forested areas.

In contrast, a much different outbreak pattern occurs in many urban areas. Here, the tussock moth typically attacks spruce trees grown as ornamentals. Outbreak cycles extend over several years, seldom following the outbreak cycle common in forested areas. Rarely are trees totally defoliated, but top-kill is common when the larvae are plentiful.

Resources Affected

Effects on Trees and Forests. The young larvae eat the underside of new needles first. Later, the larvae eat older needles or cut the needles off near the base, leaving them entangled in silken webbing. Typically, defoliation starts in the top of the tree and progresses downward (fig. 7). Defoliated trees turn reddish brown by midsummer.

The feeding of the larvae can affect the tree in various ways,

depending primarily on the density of larvae:

- Height and diameter growth can be slowed.
- The tops of trees may die.
- Heavy defoliation can kill the entire tree.

Low larval densities may reduce growth or cause top-kill. Even though defoliation may not be severe enough to kill the tree, the upper part of the crown may die. Top-kill may occur in as many as half the trees that have had 50 to 75 percent of their foliage removed. Growth recovery is not complete until the fourth or sometimes the fifth year after an outbreak subsides.

When larvae are plentiful, they can strip trees so completely of their foliage that the trees die within a year. Tree mortality can be very severe when stands are 75 to 100 percent defoliated. This mortality, however, does not occur uniformly throughout a stand. Scattered groups of trees have higher tussock moth populations. These trees often occur in clumps of 1 to 50 acres (0.4 to 20 ha).

Pest Complexes. Bark beetles attack trees weakened by tussock moth defoliation. In true fir stands, the fir engraver and a roundheaded borer are the most common bark beetles attacking recently killed and dying trees. In Douglas-fir stands, the Douglas-fir beetle will attack sawlog-sized trees previously damaged by feeding of the tussock moth. Bark beetle-caused mortality may continue for 4 years after a tussock moth outbreak subsides.

Effects on Other Resources. The effects on recreation, esthetics, and property values depend on the severity of an outbreak and the damage it causes.

If trees are killed or defoliated, more sunlight reaches the floor of the forest, and grass and forbs—forage for livestock and big game—will increase. When trees refoliate and new trees replace dead ones, the grasses and forbs return to normal. Light defoliation, therefore, affects forage production very little and only for a short time. On the other hand, severe defoliation can substantially increase forage production, especially when tree mortality occurs.

When defoliation is severe, water yields will increase, but only until an area revegetates. Consequently, the increased water available downstream is a temporary effect.

When mortality occurs, the fire hazard and related protection ex-

Figure 5. Summary of Douglas-fir tussock moth outbreaks from 1927 to 1983.

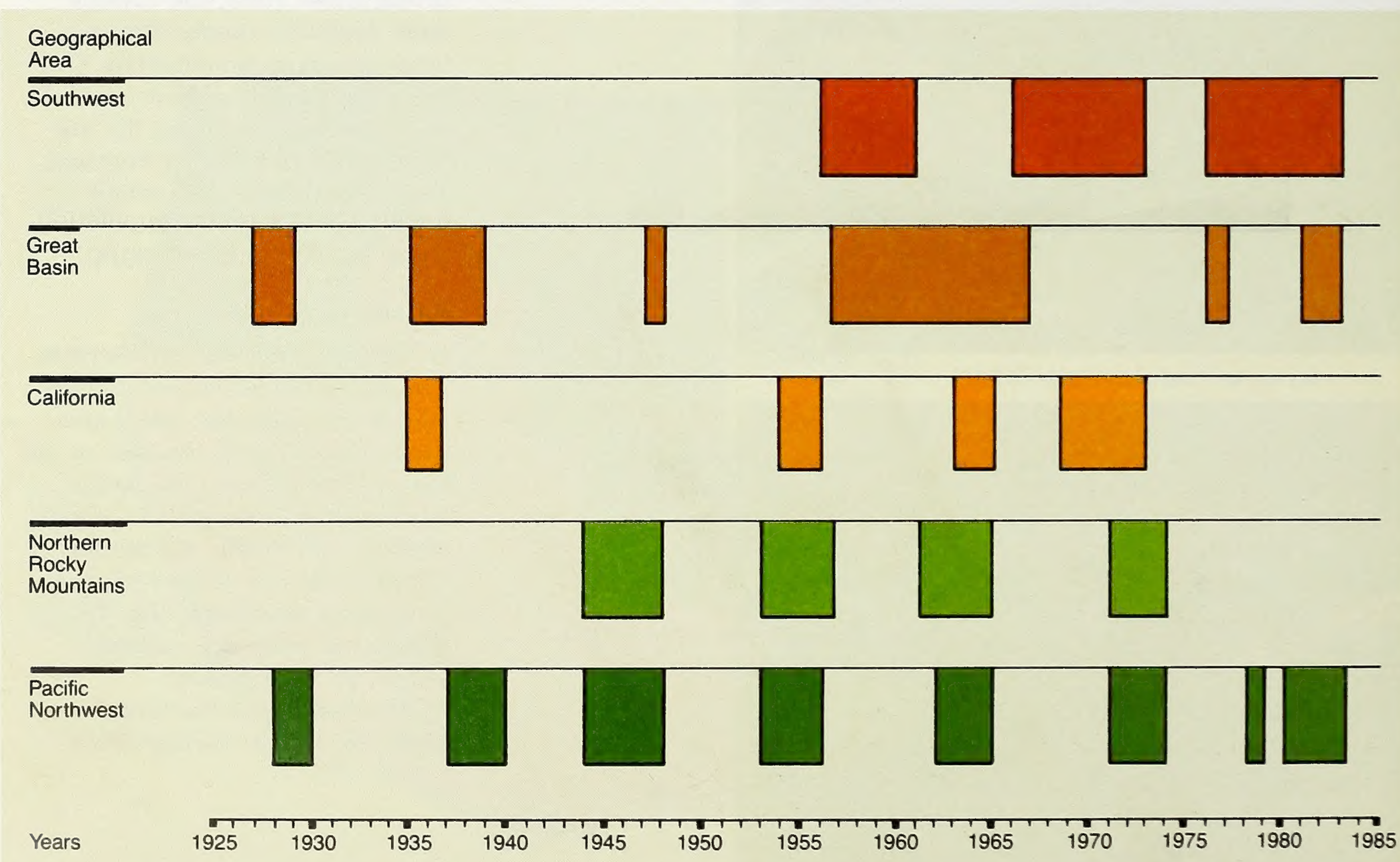
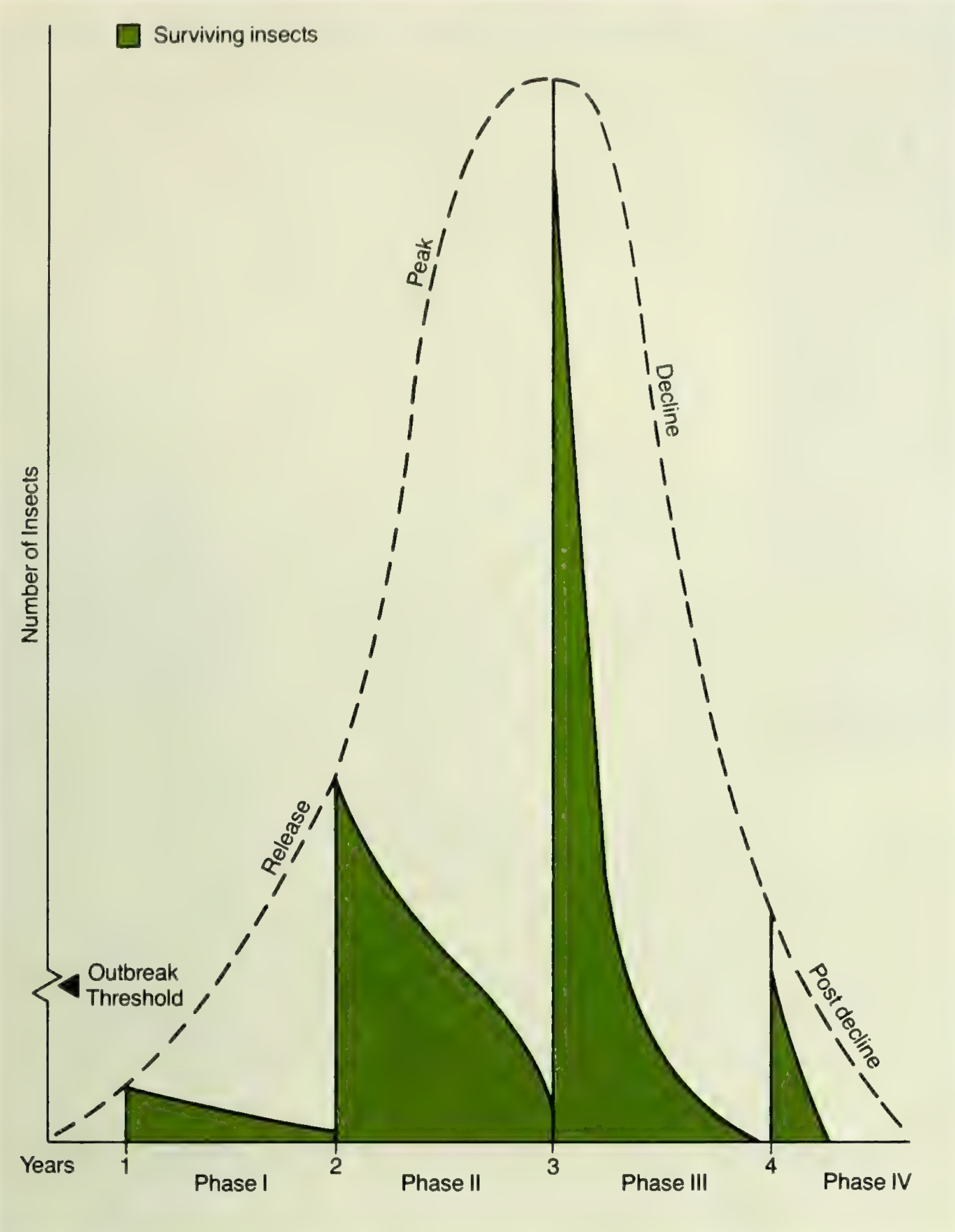


Figure 6. **Douglas-fir tussock moth outbreak sequence.**



Source: The Douglas-fir Tussock Moth: A Synthesis. Technical Bulletin 1585. Martha H. Brookes, R.W. Stark, and Robert W. Campbell. U.S. Department of Agriculture, Forest Service. 1978.

penses increase. As dead trees accumulate, the likelihood of catastrophic fires increases. Eventually, fallen dead trees decay, and the fire hazard subsides.

The larvae, pupal cases, and adults of the Douglas-fir tussock moth are covered with tiny, irritating hairs. The hairs contain a chemical substance that causes an allergic reaction, known as tussockosis, in many people. Surveys have found 75 to 90 percent of the people coming in contact with these hairs will develop a temporary allergy.

Pest Status From 1979 to 1983

Outbreaks of the Douglas-fir tussock moth during the 5 years from 1979 to 1983 were relatively small. Areas of visible defoliation are mapped in figure 8. Defoliation in urban areas is not included on the maps.

The largest areas of defoliation occurred in Washington and Idaho (table 1). But surveys in the fall of 1983 indicate that populations were declining in southwest Idaho and that populations in northeast Washington also were in various stages of collapse.

Because populations did not build up enough to cause serious losses, no major control efforts were needed; however, 1,400 acres (567 ha) were treated in New Mexico during 1979. A nuclear polyhedrosis virus was used to treat areas where populations were high enough to cause visible defoliation and where defoliation was likely to occur in the near future.

Despite its relatively innocuous status in the early 1980's, the Douglas-fir tussock moth remains a threat. Within 1 or 2 years, populations can build to outbreak conditions. Forest managers are often caught unawares; serious tree damage can occur before anyone knows that an outbreak is in progress.

Prevention/Suppression

Trapping. Traps baited with synthetic female sex pheromone have been used in some areas since 1979 to monitor population dynamics. These traps are hung outside during the summer. The number of male moths captured indicates the number of larvae to expect the following spring. Where traps average less than 25 moths per trap, the tussock moth population is small enough that defoliation is unlikely to occur within the next 2 years. Where traps average 25 or more moths per trap, populations may reach serious levels within 2 years. If pheromone-baited traps are used for consecutive years, population trends can be established (Daterman and others 1979).

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***Figure 7.* The top of this Douglas-fir near Summerville, OR, has been defoliated by the tussock moth.**

The need to treat Douglas-fir tussock moth outbreaks must be determined by comparing the total impact of an uncontrolled outbreak with the resources that would be saved if the outbreak were treated. When populations are controlled, several types of measures are commonly used, such as a combination of insecticide treatment and silvicultural treatment.

Insecticide Treatment. Many insecticides have been tested, and rejected, for direct control of the tussock moth. Only two chemicals, acephate and carbaryl, are currently registered for aerial application against the Douglas-fir tussock moth in forest stands. Other chemicals are registered for moth control on ornamental trees.

Biological agents have also been approved for use against the tussock moth. The bacterium *Bacillus thuringiensis* can be applied both from the air to forest stands and from the ground to ornamental trees. A laboratory-cultured nuclear polyhedrosis virus is also approved for control applications, but it is not available to private homeowners.

Silvicultural Treatment. In recent years, we have identified some of the factors that increase the risk of a stand being defoliated by the tussock moth.

Stands located on the upper slopes, for example, are more likely to be defoliated than stands on the lower slopes. Stands exposed to intense solar radiation on steep, south-facing slopes are more susceptible than those growing on less exposed sites. And trees growing on volcanic ash soils are less susceptible to defoliation.

The condition of the stand also affects the likelihood of defoliation. Studies have found that the hazard increases as stand density increases. During periods of drought, denser stands are more stressed and, therefore, more susceptible. Stands with multistoried structures are at higher risk than single-storied stands.

In addition, species composition may affect stand susceptibility. Usually, stands with a larger proportion of true firs will be more seriously defoliated than stands with Douglas-fir as a major component. Risk also increases with age. Trees less than 50 years old are at low risk, regardless of species composition, stand structure, or stand density.

***Table 1.* Acres defoliated by the Douglas-fir tussock moth in the Western United States from 1979 to 1983**

State	1979	1980	1981	1982	1983
			Acres		
Oregon	0	0	0	0	20
Washington	0	0	0	1,550	17,530
Idaho	0	0	180	4,000	14,200
Montana	0	0	0	0	0
Wyoming	0	0	0	0	0
Colorado	0	0	0	0	0
California	0	0	0	0	0
Nevada	0	0	0	0	0
Utah and Arizona	0	0	0	0	0
New Mexico	1,600	100	0	0	0

Source: Data from aerial surveys conducted by Forest Service and State agencies.

Figure 8. **Douglas-fir tussock moth defoliation from 1979 to 1983.**

Outlook

Although we cannot predict which specific stands will be defoliated, we have found that tussock moth populations tend to be cyclic. Populations tend to increase at 7- to 9-year intervals; outbreaks last 3 to 4 years. Further, we have found that outbreaks are generally synchronous—what happens in one geographic area is mirrored in another. In 1983, all indicators pointed to a 7- to 9-year period of low populations in the northern Rocky Mountains, Pacific Northwest, California, and in most of the Great Basin.

A new population management technique shows promise: a synthetic pheromone can be used to disrupt mating (Sower and others 1983). The pheromone comes in hollow fibers and is applied by helicopter. The number of matings was reduced as much as 81 percent when the synthetic pheromone was applied in British Columbia, Canada.

Although future control activities will still rely on chemicals, new programs will place a greater emphasis on natural and biological controls. The laboratory-cultured nuclear polyhedrosis virus, which the USDA Forest Service developed, will be a major component of tussock moth management programs. Land managers and foresters will use what they have learned about environmental factors and stand susceptibility to forestall outbreaks and to reduce damages when outbreak cycles do occur.

A Regional Nuisance Becomes a National Dilemma

Written by Robert D. Wolfe

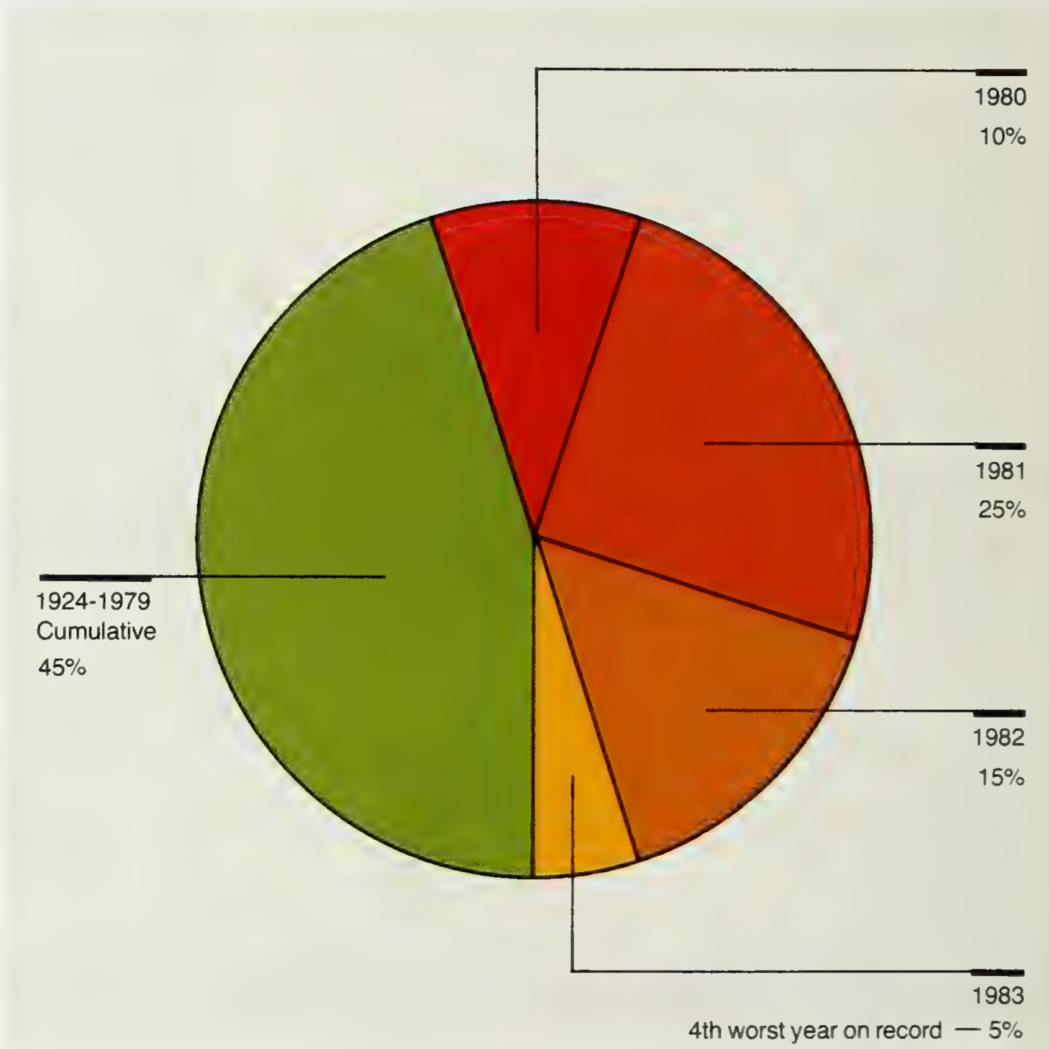
From 1979 to 1983, defoliation caused by the gypsy moth reached unprecedented levels: the years from 1980 to 1983 were the worst on record. Defoliation during the 5-year period 1979–83 totaled more than all the defoliation recorded during the previous 55 years (fig. 1). Few people would have predicted that this insect could cause such extensive damage.

The gypsy moth was introduced into this country from Europe in 1869. From its toehold outside Boston, MA, the moth established itself throughout New England, New Jersey, and Pennsylvania. During the 1980's, the gypsy moth spread into Delaware, Maryland, and into portions of Virginia and West Virginia. Isolated infestations have been found in many States, including Arkansas, California, North Carolina, Oregon, and Washington.

Like other defoliating insects, the gypsy moth does its damage during the larval stage. In the Northeast, the larvae emerge from egg masses in late April or early May. After they hatch, some larvae crawl to treetops and hang suspended on silken threads. These larvae are easily picked up by the wind and can be carried for several miles or more. As they feed, the larvae pass through several instars, shedding their outer skin as they grow (fig. 2). When population levels are high, the larvae remain in the trees, feeding day and night until mature enough to pupate.

The male moths, which emerge from the pupae in late June, are strong fliers; female moths cannot fly. Instead, the females lure the males by emitting a strong sex pheromone. After they mate, the female deposits her eggs in an oval mass of as many as 1,000 eggs (fig. 3). Then, both moths die. Larvae emerge from the egg masses the following spring.

Figure 1. **Acreage defoliated by gypsy moth.**



The larvae feed on the leaves of more than 300 woody plants (table 1). In the Northeast, the larvae prefer the oak species, especially the white oak group. Older larvae feed on the foliage of several species that younger larvae normally avoid, such as hemlock, pine, and spruce. During outbreaks, however, the larvae will feed almost indiscriminately. As the natural spread of the gypsy moth continues, the number of plant species likely to be defoliated will increase.

Historical Perspective

Gypsy moth outbreaks are cyclic; populations periodically build to epidemic levels. The first outbreak occurred in 1889—about

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Figure 2. A fourth instar, about 1 inch (25 mm) long, showing the identifying pattern of five pairs of blue spots followed by six pairs of brick-red spots.

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Figure 3. Whitish female moths and egg masses. The egg masses, attached to the bark, are covered with fine yellow hairs.

F–705631

Figure 4. **Heavy gypsy moth defoliation in Pennsylvania.**

20 years after the moth was introduced. In an attempt to eradicate the moth, the insecticide Paris green was used, and creosote or acid was applied to the egg masses. Infested trees were burned, and tree trunks were banded with strips of burlap. Since 1889, State and Federal agencies have, at various times, attempted to eradicate the gypsy moth from portions of the Northeast.

Shortly after the turn of the century, parasites and predators from Europe and then Asia were introduced to control outbreak cycles. Over the years, more than 50 species have been introduced into infested areas, with limited degrees of success. Although they have caused increased mortality in gypsy moth populations from time to time, the parasites and predators have failed to effect any significant moderation of the cyclic outbreaks.

Today, the insect is so permanently established throughout the Northeast that eradication is virtually impossible. Efforts are now directed at controlling the insect and its damage in selected parts of the total outbreak area, particularly recreation areas and forested communities. Only a small portion of the total outbreak area is treated in any year.

The gypsy moth has also been found as far removed from the generally infested area as California and Florida, and eradication has been possible in some isolated areas. Gypsy moth egg masses and pupae spread into these isolated areas attached to movable items, such as nursery plants, logs, firewood, recreational vehicles, or outdoor household articles. Eradication techniques, like the mass trapping of male moths or the release of sterile life stages, are generally used in combination with an earlier application of an insecticide.

***Table 1.* Trees favored by the gypsy moth**

Preferred	Less Preferred		Least Preferred
Oak	Maple	Sourwood	Ash
Hawthorn	Buckeye	Pine	Holly
Paper birch	Hickory	Cottonwood	Mulberry
Gray birch	Red bud	Cherry	Yellow-poplar
Apple	Hackberry	Hemlock	Sycamore
Sweetgum	Dogwood	Elm	Locust
Tamarack	Persimmon	Serviceberry	Fir
Aspen	Beech	Black walnut	Spruce
Willow	Magnolia	Sassafras	Butternut
American basswood	Tupelo	Witchhazel	Catalpa

Resources Affected

Timber. The impact on the timber resource depends upon the abundance of host trees and on site and stand conditions.

Throughout the infested Northeast, the gypsy moth larvae prefer to feed on oaks. Generally, vigorous oaks can withstand one or two consecutive heavy defoliations, but suppressed oaks and those in poor condition may die after one defoliation (fig. 4). When preferred hosts are defoliated, the larvae migrate to adjacent hosts.

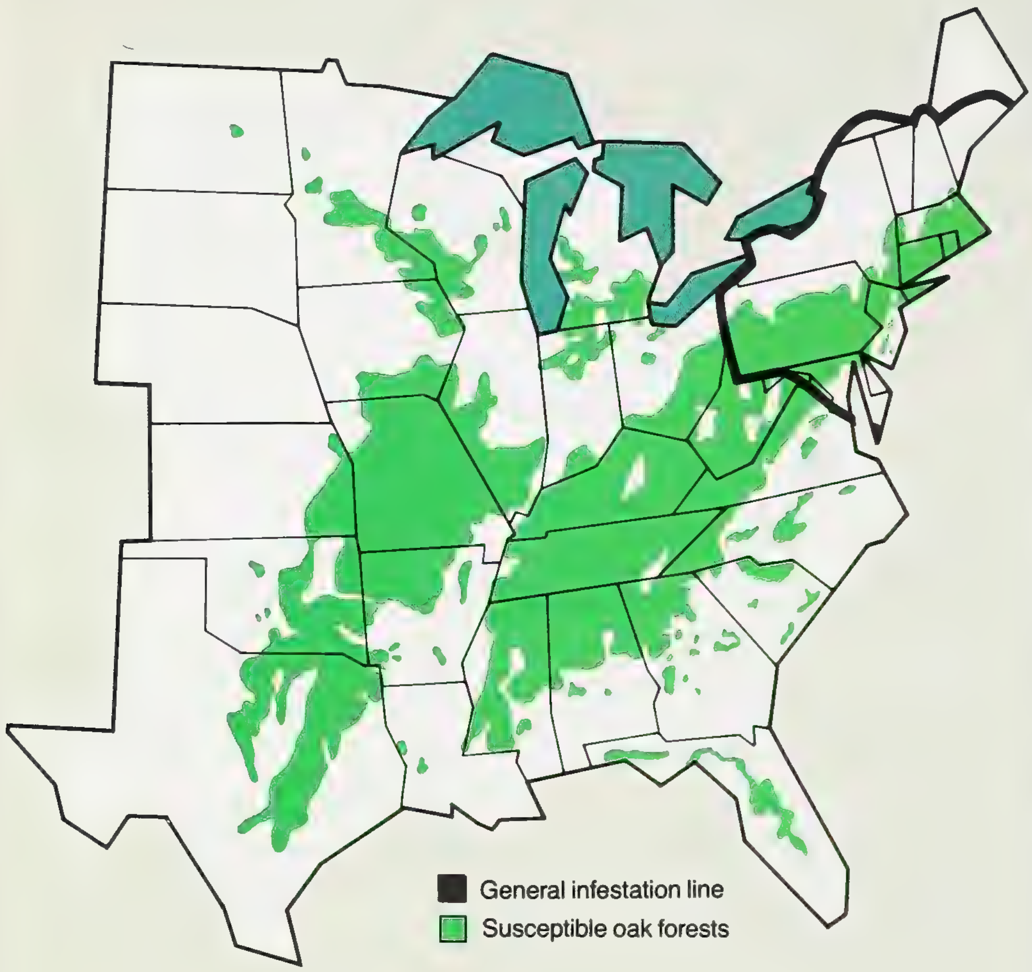
When deciduous trees, oaks, for example, are stripped of more than 50 percent of their leaves, the trees usually refoliate by midsummer. But the production of new foliage further stresses the tree. To refoliate, the tree may deplete its stored food reserves. Trees that have been previously stressed or weakened by other agents may have insufficient food reserves to completely refoliate, and their upper crown branches may die. In addition, stressed trees are often attacked and killed by other pests, such as the two-lined chestnut borer or the armillaria root disease fungus.

Depending on its intensity, defoliation may also reduce the tree's radial growth by 30 to 50 percent (McManus 1980). But if no defoliation occurs in the following 1 or 2 years, many stressed trees will survive and regain their former growth rates.

Hardwood tree mortality may, depending on the site, encourage the growth of red maple and other more shade-tolerant hardwoods. In some cases, the changes in stand composition may be regarded as beneficial: such areas may be less susceptible to future gypsy moth defoliation.

In the East, an estimated 251 million acres (102 million ha) of commercial hardwood forests, that is, forests capable of producing 20 cubic feet of wood per acre per year (0.23 m^3/ha/year), are susceptible to gypsy moth defoliation. About one-fourth of this area is already infested. The remaining 188 million acres (76 million ha) comprise what is called the susceptible area, hardwood forests that the gypsy moth may eventually infest (fig. 5). In general, this susceptible area contains better hardwood growing sites, greater oak stocking, and higher timber quality than most of the area already infested. As the insect spreads south and west into these forests, mortality and associated value losses are expected to increase.

Figure 5. **Susceptible hardwood forests of the East and the infested area of the Northeast, 1983.**



Wildlife. Hardwood mortality benefits some species but harms others. Openings in mature hardwood stands may encourage the proliferation of abundant understory cover, vegetation often beneficial to deer and grouse. Cavity nesting birds and song birds may also benefit. On the other hand, such areas produce less of the seed crop needed by other wildlife species, such as turkey and squirrels.

Water. During outbreaks, the larvae's excrement, called frass, may temporarily increase the amount of nutrients, thus reducing water quality. In municipal water sources, the increased nutrient content often causes algae to grow rapidly, further reducing water quality.

Defoliation affects the quantity of water. In watershed areas, heavy defoliation can increase run-off, erosion, and streamflow. When defoliation reduces the shade adjacent to small streams, water temperatures may rise. These effects, however, are usually temporary, lasting only until the trees refoliate.

Table 2. **Acres defoliated by gypsy moth from 1979 to 1983**

State	1979	1980	1981	1982	1983
			Acres		
Connecticut	7,486	272,213	1,482,216	803,802	153,239
Delaware	10	0	500	1,265	2,992
Maine	23,180	221,220	655,841	574,537	16,285
Maryland	0	3	8,826	9,162	15,870
Massachusetts	226,260	907,075	2,826,095	1,383,265	148,133
Michigan	100	5	18	92	457
New Hampshire	5,980	183,999	1,947,236	878,273	560
New Jersey	193,700	411,975	798,790	675,985	340,285
New York	162,275	2,449,475	2,303,915	825,629	290,843
Pennsylvania	8,552	440,500	2,527,753	2,351,317	1,360,824
Rhode Island	655	43,830	272,556	658,000	53,880
Vermont	15,411	75,095	48,979	9,864	0
Total	**643,609**	**5,005,390**	**12,872,725**	**8,171,191**	**2,383,368**

Esthetics. Defoliated vistas and forests look unsightly. What impact, if any, defoliation has on the tourist industry in affected recreation areas is difficult to assess; however, defoliation and mortality can be so unappealing that the number of visitors often declines substantially.

In residential areas, heavy defoliation reduces the cooling and humidifying effects of shade trees. When tree mortality occurs, property value may fall, and homeowners may have to pay expensive tree removal and replacement costs.

Nuisance. The gypsy moth often becomes a nuisance when larvae migrate from defoliated trees in search of additional food or protected pupation sites. Larvae invade houses, garages, and sheds or accumulate in large numbers under eaves, porches, or window sills. Homeowners often spend considerable time and money cleaning pupal cases and egg masses from exterior surfaces. Damaged exterior surfaces may require repainting. And people sensitive to the hairs of the larvae may require medical treatment to reduce allergic reactions.

Status From 1979 to 1983

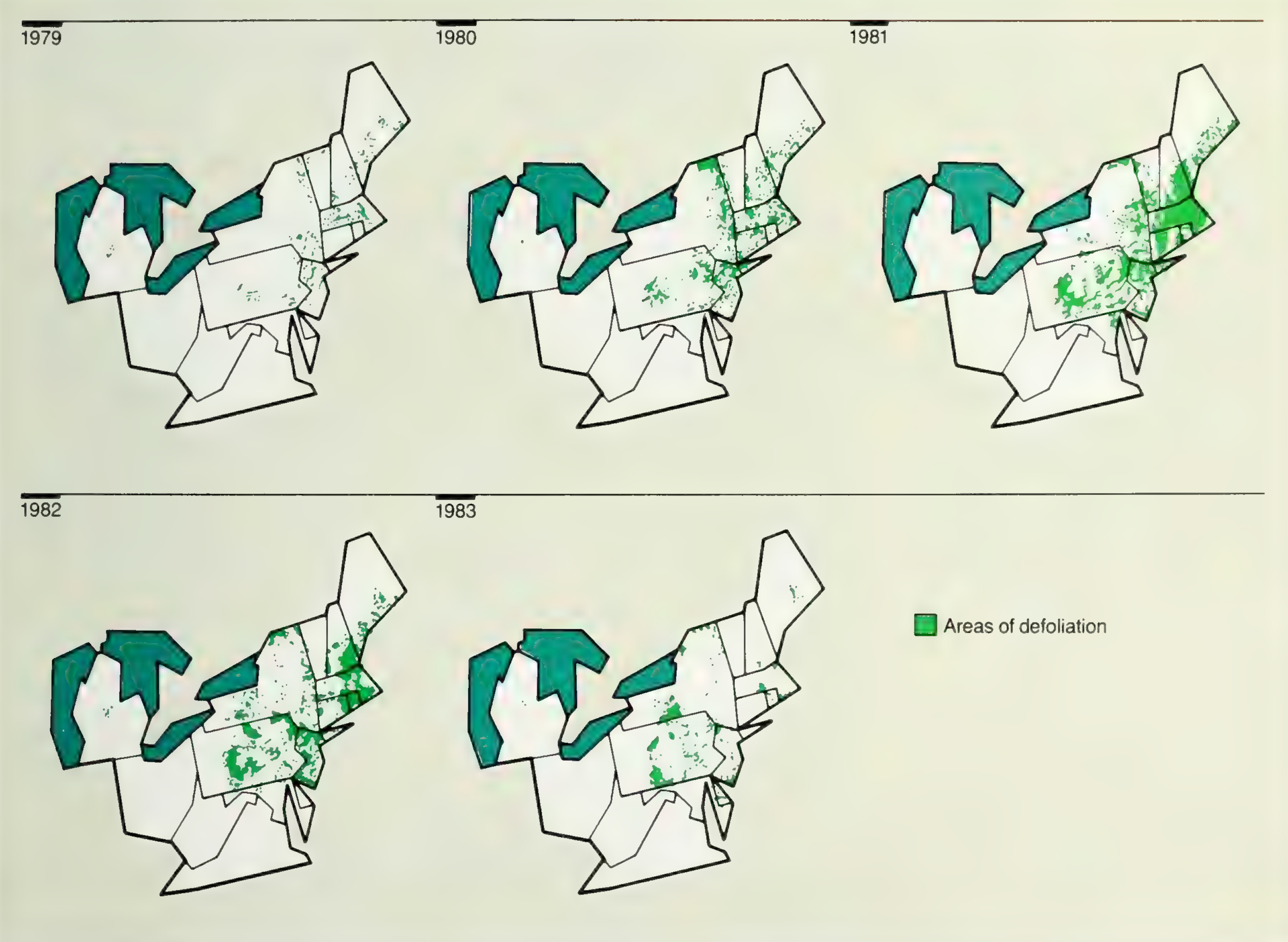
The most recent outbreak peaked in 1981 when a record 12.8 million acres (5.18 million ha) was defoliated (figs. 6 and 7 and table 2). This level of defoliation was completely without precedent.

Weather may have been a factor affecting defoliation over the 5-year period. Apparently, weather may have a greater impact on gypsy moth populations over large geographic areas than any of the biological agents. Extremely cold winter weather or periods of thawing and freezing in midwinter may result in extensive egg mortality. Cold, rainy weather in the spring may stress the young larvae and encourage the development of disease.

Prevention/Suppression

Federal and State agencies are

***Figure 6.* Gypsy moth defoliation from 1979 to 1983.**



cooperatively evaluating high-altitude infrared photography to obtain information on the location and intensity of gypsy moth defoliation (fig. 8). An advanced version of the U-2 aircraft, the ER-2, flies over the infested areas. The plane is equipped with an optical bar camera. From 65,000 feet above sea level, the camera scans an area 37 nautical miles long and 1.5 nautical miles wide. Maps made from these photographs have been more accurate than maps plotted with the conventional sketchmapping techniques.

A number of strategies have been tried to control populations of gypsy moth. These strategies include not only introducing parasites and predators but also encouraging native predators. Numerous birds, mammals, amphibians, reptiles, and invertebrates feed on the various life stages of the gypsy moth and may keep populations at innocuous levels. Although these predators have little effect upon the sheer number of gypsy moths during outbreaks, a naturally occurring nuclear polyhedrosis virus often collapses populations in parts of an outbreak area. This virus has been produced in the laboratory and developed into a biological insecticide that is still being tested.

Table 3 lists the States conducting cooperative suppression from 1979 to 1983 and the acres treated. During these 5 years, the type of aircraft used to apply insecticides changed. In 1979, fixed-wing aircraft were used over 80 percent of the treated acreage; by 1983, helicopters were being used over 77 percent of the treated acreage.

Another trend was toward greater use of biological insecticides. In 1979, approximately 84 percent of the acreage was treated with chemical insecticides; by 1983, however, 70 percent of the acreage was treated with the bacterium *Bacillus thuringiensis* (B.t.). The shift to the bacterium is the result of several factors: the improved formulations and effectiveness of B.t.; its reduced cost; the public's preference for the

Figure 7. **Acres defoliated by gypsy moth.**

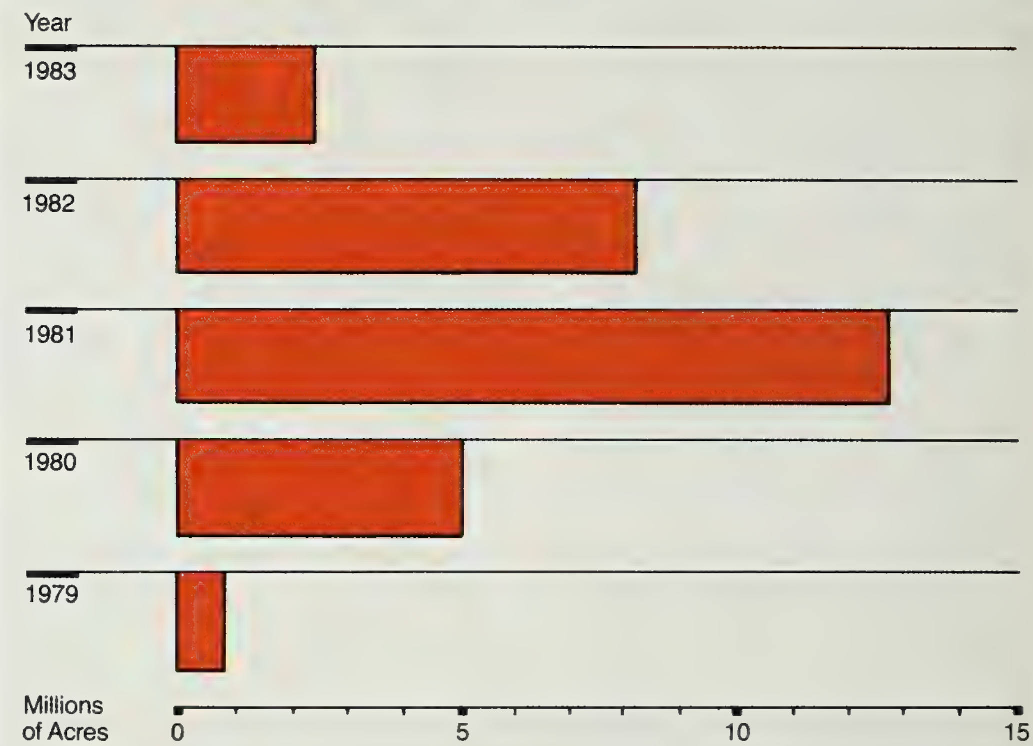


Table 3. **Gypsy moth suppression projects conducted cooperatively by the USDA Forest Service and State agencies from 1979 to 1983[1]**

State	1979	1980	1981	1982	1983
			Acres		
Delaware	0	0	0	0	1,100
Maine	0	0	400	1,910	0
Maryland	0	0	0	48,364	120,082
Massachusetts	0	0	0	4,160	1,598
New Hampshire	0	0	0	440	0
New Jersey	41,500	35,500	75,800	101,740	81,045
New York	17,400	20,000	63,900	10,284	0
Pennsylvania	10,900	24,800	178,200	494,743	371,723
Rhode Island	0	0	22,600	64,816	6,477
Vermont	3,100	0	0	300	0
West Virginia	0	0	0	0	16,735
Total	**72,900**	**80,300**	**340,900**	**726,757**	**598,760**

[1]Although defoliation occurred in Connecticut and Michigan, these States conducted no cooperative suppression projects. West Virginia reacted quickly to the natural movement of the gypsy moth into that State and treated areas based on surveys rather than on actual defoliation.

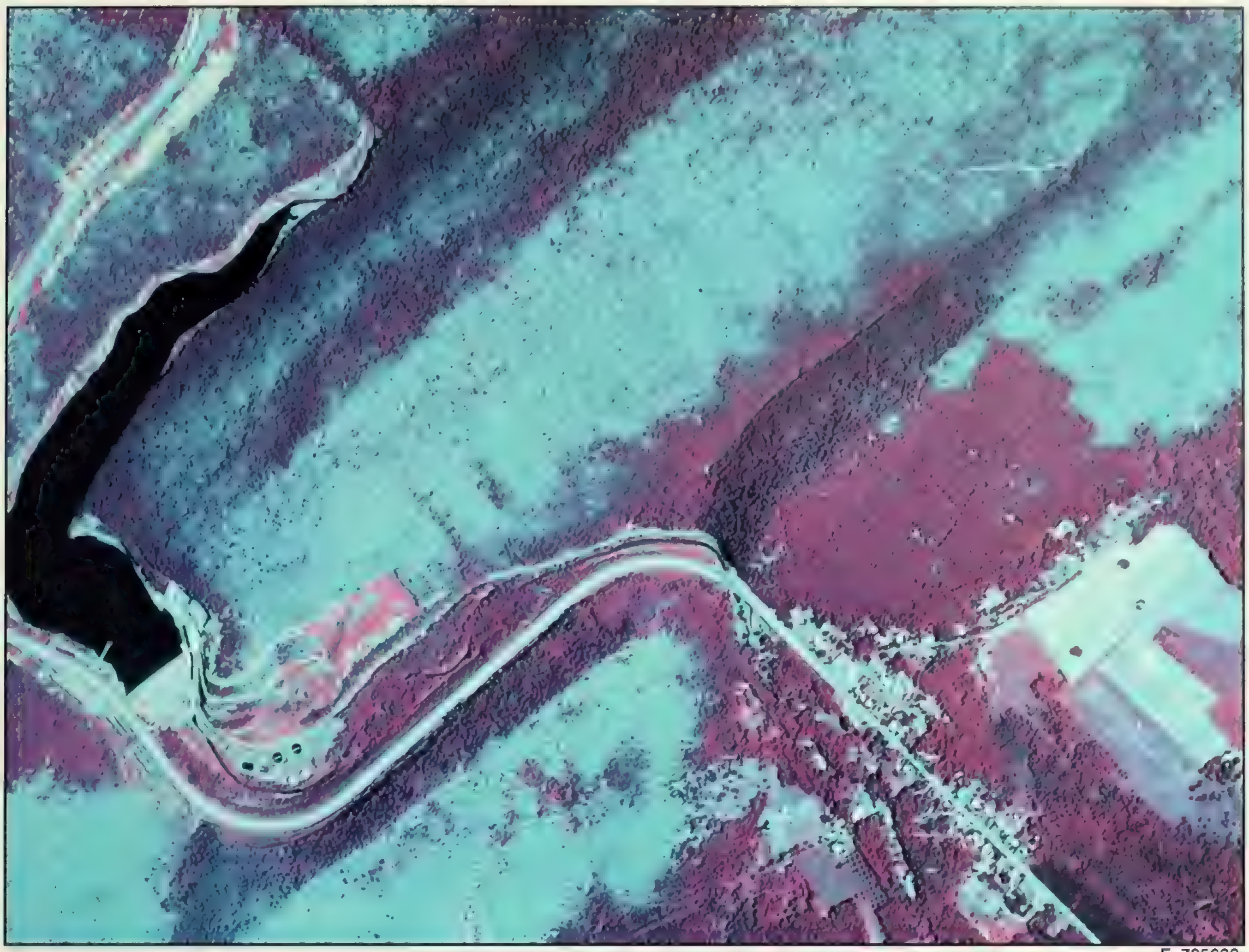


Figure 8. **High-altitude infrared photography over Mifflin County, PA. Gypsy moth defoliation appears gray blue; undamaged forests photograph bright red; and water photographs black.**

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biological insecticides; and the increased cost of chemical insecticides containing petroleum oils. Work continues on the development of more effective strains of B.t. and improved formulations of the nuclear polyhedrosis virus.

Furthermore, the use of the insecticide diflubenzuron, an insect growth regulator that interferes with the molting of the larvae, increased 17 percent from 1979 to 1983.

Isolated infestations have been successfully eradicated. Disparlure, a synthetic sex pheromone used to prevent or disrupt mating, has been effective in eradicating low-level gypsy moth populations in several areas. Similar results have been achieved using applications of insecticides in combination with disparlure-baited traps. Small isolated populations have also been eradicated by releasing sterilized male moths. Sterilized males mate with wild females, which then lay sterile eggs. Larvae never emerge from the sterile eggs.

Outlook

Undoubtedly, the gypsy moth will continue its spread south and west. Consequently, all the susceptible hardwood forests from Maine to Louisiana could become infested. We can only speculate on how rapidly the insect will spread and what impact it will have on the hardwood forests.

In the generally infested areas, gypsy moth control will rely on insecticides for some time to come. Eventually, however, silvicultural practices to reduce the impact of the insect may offer an alternative to insecticides in high-value timber stands. In addition, the technique of flooding an area with sterilized life stages of the moth may eventually be useful in preventing small populations within the Northeast from building to damaging levels.

One thing is certain. The gypsy moth has flourished and spread; its status has changed. This insect has grown from a regional nuisance to a full-fledged national problem.

The Conflict Between People and the Beetle

Written by Mark D. McGregor

In the West today, thousands of acres of grey trees stand as skeletal evidence of previous mountain pine beetle outbreaks. The dead trees stand ready to fuel a massive forest furnace, which needs only a spark to become an inferno. Intensive burns over vast areas can be a natural aftermath of a mountain pine beetle outbreak.

We find the mountain pine beetle almost everywhere lodgepole and ponderosa pines grow—from the Pacific Coast east through the Black Hills and from western Alberta south to Mexico. The beetle ranges from sea level in British Columbia, Canada, to 11,000 feet (3,300 m) in southern California.

The mountain pine beetle looks insignificant: it measures less than three-eighths of an inch (7 mm). Yet in 1980 this tiny insect killed almost 30 million trees.

The mountain pine beetle lives within the host tree. Adult beetles mate and lay eggs under the bark (fig. 1). When larvae emerge from the eggs, they tunnel feeding galleries in the phloem, the nutrient-carrying tissues of inner bark. These tunnels go around the tree to girdle and kill it as effectively as an axe (fig. 2).

The adult beetles also damage the host tree. Within cells at the end of the feeding galleries, larvae change into pupae and, then, into adults. The adults pick up blue-stain fungi and possibly other micro-organisms, which the beetles carry with them when they emerge and attack a new tree. The fungal spores, as well as yeast and bacterial spores, grow

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***Figure 1.* Adult beetle in perpendicular egg gallery.**

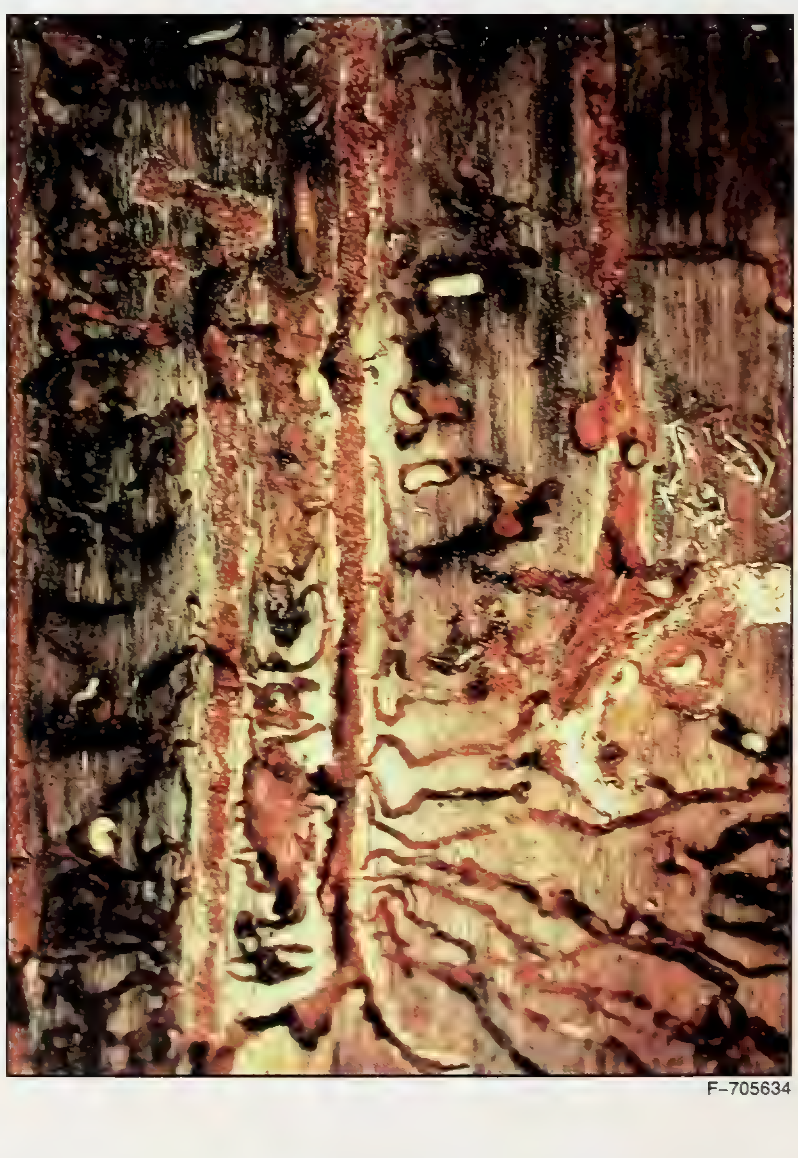

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***Figure 2.* Galleries of mountain pine beetle. The galleries form an identifying pattern in the inner bark.**

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Figure 3. **Beetle-infested lodgepole pine dying on the Flathead National Forest, MT.**

in the phloem and xylem tissues and interrupt the flow of water and nutrients.

When beetles are present in sufficient numbers, they overcome the tree. As a tree dies, its needles first turn a pale green, then light orange, and finally a bright orange red (fig. 3). This orange-red color attracts the attention of forest visitors, especially when trees are dying over millions of acres (fig. 4).

Historical Perspective

This insect has always been present in the Western United States but was not considered a serious pest until about 1900. Only as sawmills were built to produce the lumber for houses, farms, and industry did the early settlers discover that they were in competition with the beetle for the trees.

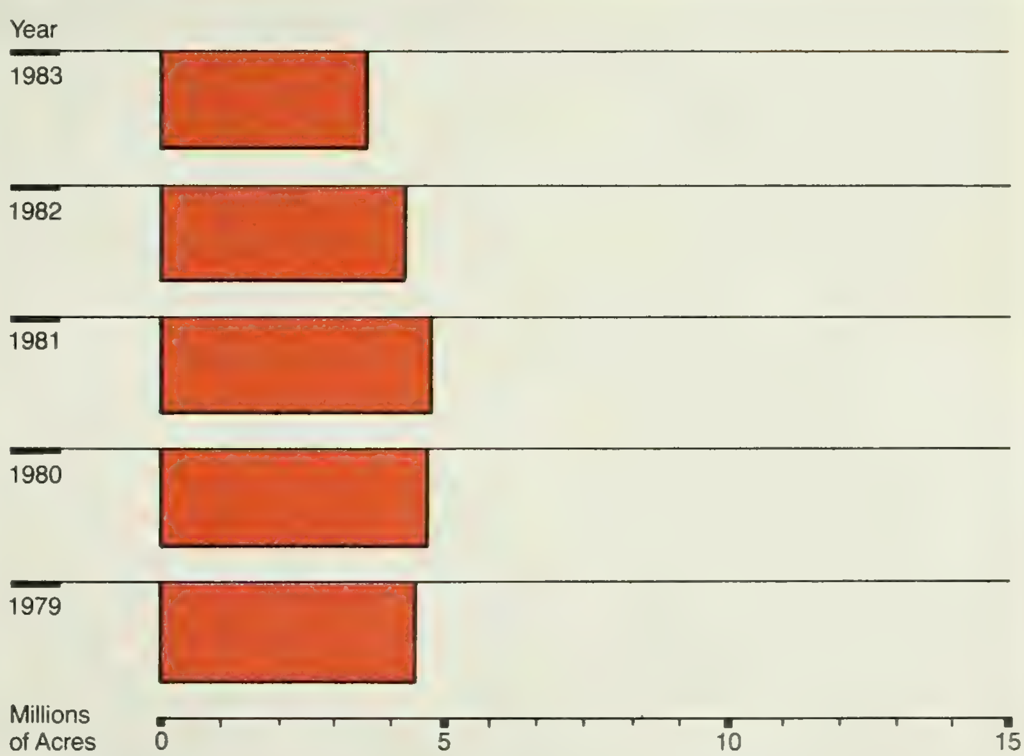
The conflict between people and the mountain pine beetle has not been resolved to this day. Since 1975, the beetle has killed an estimated 440,000 cubic feet (12,460 m³) per year (Safranyik 1978).

In the Intermountain States, a small infestation was discovered in 1953 on the north slope of the Unita Mountains in Utah. By 1958, the infestation had developed into a full-scale outbreak. Control efforts began in 1958 and continued for 10 years. But by 1965, most of the lodgepole forests in northern Utah, southern Idaho, and western Wyoming were experiencing massive outbreaks. These outbreaks continued to spread northward, sweeping through Yellowstone National Park and into the Gallatin National Forest in Montana. In Montana and Idaho, infestations now extend over 1.5 million acres (0.6 million ha).

In the Pacific Northwest, most of the damage has occurred east of the Cascade Mountains. From 1955 through 1966, 836,110 acres (338,369 ha) of lodgepole pine were infested. The current infestation started in 1967 in northwest Oregon. To date, infestations have occurred over more than 1 million acres (404,700 ha) and killed about 22.2 million cubic feet (629,000 m³).

In the Northwest, most of the damage has occurred in the Blue Mountains in eastern Oregon and southeastern Washington. Since the early 1970's, however, extensive thinning of second-growth ponderosa pine stands has drastically reduced beetle-caused losses. Mortality now occurs where ponderosa pines grow in close association with infested lodgepole pine.

Figure 4. **Acres infested by mountain pine beetle.**



Resources Affected

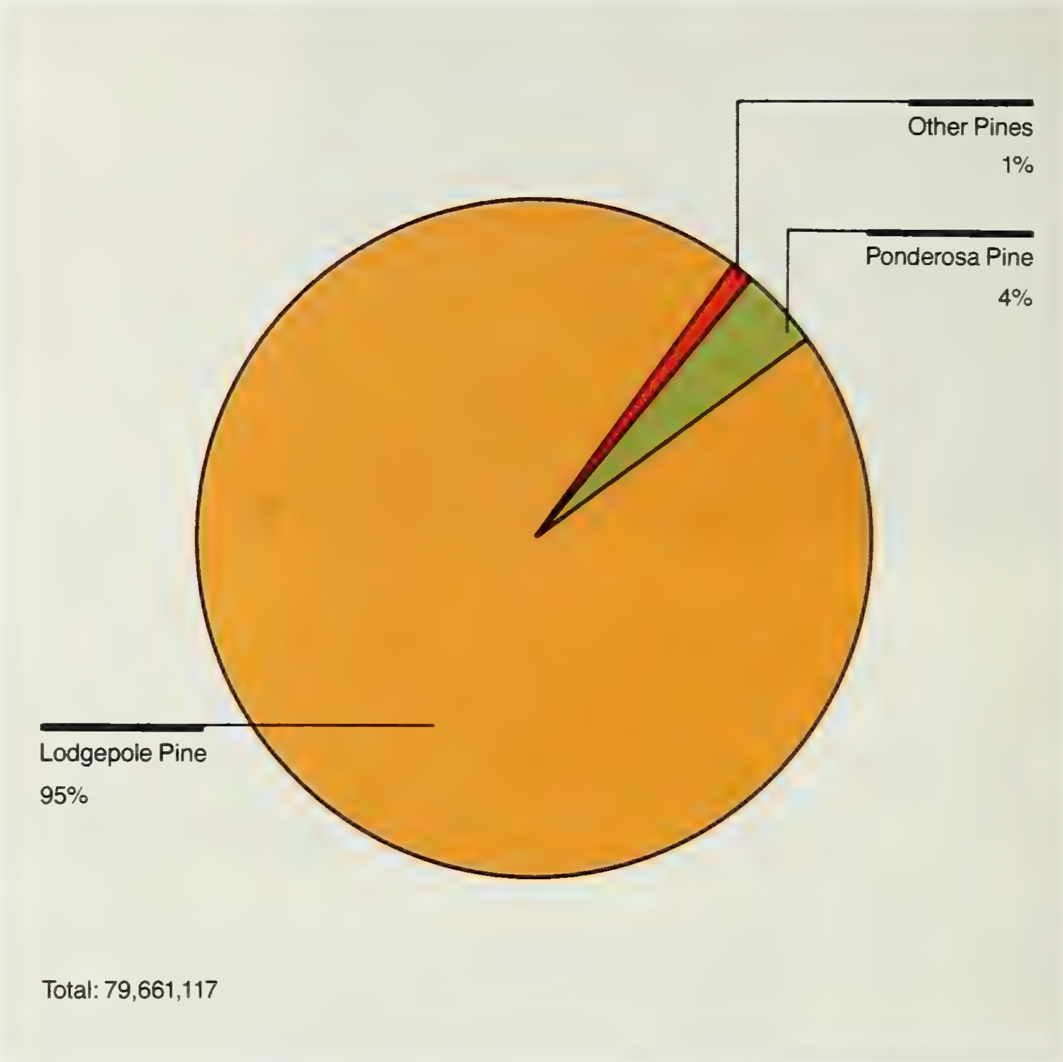
Timber. All unmanaged stands of mature and overmature lodgepole pine, of second-growth mature and overmature ponderosa pine, of mature and overmature western white and sugar pines, and of overmature whitebark and limber pines are susceptible to attack. Dead trees must be salvaged for wood or fiber 3 to 5 years after they die; otherwise, they are often not worth salvaging.

Some States have large areas of these susceptible, unmanaged mature or overmature stands. In Montana and northern Idaho, for example, an estimated 5.1 million acres (2.1 million ha) of mature lodgepole pine stands are highly susceptible. These susceptible acres include 3.7 million acres (1.5 million ha) of commercial lodgepole pine that could be expected to yield 433.3 million cubic feet (12.3 million m³) of timber. Most of these acres are not planned for immediate timber harvest; many acres are presently inaccessible. Consequently, if infestations continue to develop, spread, and intensify, the impact will be significant.

In unmanaged forests, beetle-caused mortality eventually causes large portions of the commercial forest land to become understocked. Because much of this understocked area is inaccessible, regeneration efforts would be time consuming and difficult.

Widespread tree mortality resulting from outbreaks that last several years can influence the ecosystem. Rapid ecological changes take place over large areas; watersheds are adversely affected when pine canopies are destroyed; patterns of recreational use change; the supply of dead fuelwood increases; and valuable forests are converted to less desirable species.

***Figure 5.* Trees killed by mountain pine beetle, Western United States from 1979 to 1983.**



Watershed. The damage to a watershed depends mainly on the extent and the intensity of an outbreak. After an infestation collapses, the water yield may increase as much as 30 percent. This increase can last 15 years. The water yield should decline as new stands are established.

Wildlife. Outbreaks can change the composition and distribution of wildlife because they may result in an increased mosaic of live trees and forest openings. This habitat diversity benefits many wildlife species, including deer, elk, and bear; small mammals; grouse, turkey, and other birds. But the capacity of species to adapt to changing environmental conditions varies so that animals that have specific habitat requirements may be adversely affected when pine overstories are destroyed.

Besides, if an infestation creates extensive areas of dead trees, big game species may suffer. They have less thermal cover and hiding cover. And as stands deteriorate and trees fall like jackstraws, the big game cannot move about as easily as before. Examples of the negative effects of mountain pine beetle-caused mortality on wildlife can be seen near the town of West Yellowstone, MT, and in the North Fork Flathead River drainage, also in Montana. Infestations have resulted in loss of cover for elk, deer, and grizzly bear.

Range. Under closed stands of mature lodgepole pine, livestock

forage is poor. Beetle infestations can open these stands and increase forage.

Recreation. Tree mortality affects recreation in developed sites, such as campgrounds. Some campgrounds have had to be abandoned or moved because so many trees have been killed. But campgrounds can be protected by spraying insecticides directly onto the bark of uninfested trees.

Tree mortality also reduces property values. Mountain property values in Colorado, for example, depend on the number of trees per acre. With 140 trees, an improved lot is valued at $7,645 per acre. The value of an acre drops to $7,569, $6,717, or $5,460 with 100, 50, or 10 trees, respectively.

Sometimes, dead stands have become areas for firewood gathering.

Fire Considerations. Following a mountain pine beetle epidemic, the buildup of fuel greatly increases the risk of wildfire. Current epidemics are building enormous fuel beds that will, in time, burn, unless fuel treatment occurs. The Sleeping Child Fire of 1961 in Montana, which caused enormous losses, occurred about 30 years after a large-scale outbreak.

Although fire will reduce the amount of available fuel, intensive burns over large areas may spread into other timber stands. Large areas are likely to burn, increasing waterflows and erosion, thus harming fish and causing other associated damage.

Wilderness. Infestations in wilderness areas are usually allowed to run their course, killing most of the larger lodgepole pine. Without fire, lodgepole pine stands, which are intermediate succession stages, will be replaced by climax species. With fire, some stands will regenerate to lodgepole pine, and another cy-

***Figure 6.* Mountain pine beetle infestations, Western United States from 1979 to 1983.**

cle of beetle infestations will occur.

Resources adjacent to wilderness areas may be partially protected from the buildup of populations inside wildernesses through intensive management. A buffer strip of managed trees inside the wilderness area may also be necessary to protect adjacent lands.

Status From 1979 to 1983

From 1979 to 1983, the mountain pine beetle killed more than 79 million pines: 95 percent of the trees killed were lodgepole pine; 4 percent were ponderosa pine; and 1 percent were other pines, including western white pine, sugar pine, and high-elevation whitebark pine (fig. 5).

The location of outbreaks during this 5-year period is shown in figure 6. This information was compiled from aerial surveys.

In each Western State, the estimates of acres infested (table 1) and trees killed (table 2) are divided into host type: lodgepole, ponderosa pine, and other pines. These estimates include lands of all ownership and were compiled from data provided by USDA Forest Service regions. Because of the extensive acreage of susceptible host type in Oregon and Montana, these two States had the greatest amount of tree mortality.

Prevention/Suppression

As new information has become available, pest managers have been encouraging land managers to implement sound pest management strategies.

Hazard rating models (Amman and others 1977; Cole and McGregor 1983) have provided useful tools to identify stands where risk of loss is highest. Since 1979, about 965 million cubic feet (27.3 million m^3) have been removed from 857,731 acres (347,119 ha) to salvage mortality, suppress small infestations, and prevent outbreaks from developing (table 3). Insecticides have also been used to control the mountain pine beetle. Over the 5-year period, Colorado treated 264,226 infested trees to reduce beetle populations and minimize future tree mortality. In addition, Colorado and the USDA Forest Service in Idaho, Montana, and Utah treated 61,379 high-value, uninfested green trees in campgrounds, summer home areas, and recreation sites to prevent beetle from attacking the trees.

Fuelwood cutting has increased since 1979. Removing the dead wood reduces the fire hazard connected with beetle outbreaks.

In some areas being managed for timber, regular harvests coupled with fuelwood cutting and prescribed burning can reduce future epidemics by creating a greater diversity of age classes and tree species.

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Figure 7. **Montana, 1982. Thousands of acres of lodgepole pine in Glacier National Park were killed by the mountain pine beetle.**

Table 1. **Acres of lodgepole, ponderosa, and other pines (sugar pine, western white pine, and whitebark pine) with mountain pine beetle infestations—from 1979 to 1983**

State	Host type	1979	1980	1981	1982	1983
		Acres				
Arizona	Lodgepole pine	NA[1]	NA	NA	NA	NA
	Ponderosa pine	97,920	25,210	14,950	3,815	315
	Other pines	NA	NA	NA	NA	NA
	Total	**97,920**	**25,210**	**14,950**	**3,815**	**315**
California	Lodgepole pine	—[2]	—	—	—	10,000
	Ponderosa pine	—	—	—	—	—
	Other pines	—	—	—	—	—
	Total					**10,000**
Colorado	Lodgepole pine	33,000	35,000	37,500	120,000	215,000
	Ponderosa pine	350,300	64,000	70,000	63,000	22,000
	Other pines	0	0	0	0	0
	Total	**383,300**	**99,000**	**107,500**	**183,000**	**237,000**
Idaho	Lodgepole pine	639,569	676,795	676,300	542,854	48,803
	Ponderosa pine	33,521	35,415	33,440	27,340	8,612
	Other pines	0	1,640	100	1,130	30
	Total	**673,090**	**713,850**	**709,840**	**571,324**	**57,445**
Montana	Lodgepole pine	1,333,807	2,129,953	2,322,437	1,994,728	1,392,946
	Ponderosa pine	44,269	70,872	76,393	116,206	2,042
	Other pines	41,070	4,795	19,311	31,193	97,086
	Total	**1,419,146**	**2,205,620**	**2,418,141**	**2,142,127**	**1,492,074**
Nevada	Lodgepole pine	0	0	0	0	0
	Ponderosa pine	0	890	2,280	0[3]	505
	Other pines	0	0	0	0	0
	Total	**0**	**890**	**2,280**	**0**	**505**
New Mexico	Lodgepole pine	NA	NA	NA	NA	NA
	Ponderosa pine	76,160	9,300	8,650	2,890	1,990
	Other pines	NA	NA	NA	NA	NA
	Total	**76,160**	**9,300**	**8,650**	**2,890**	**1,990**
Oregon	Lodgepole pine	726,850	817,800	522,080	615,390	1,021,700
	Ponderosa pine	362,770	179,860	67,630	55,580	94,940
	Other pines	10,350	5,280	1,810	31,223	12,520
	Total	**1,099,970**	**1,002,940**	**591,520**	**702,193**	**1,129,160**
South Dakota	Lodgepole pine	NA	NA	NA	NA	NA
	Ponderosa pine	300,000	300,000	380,000	5,500	11,000
	Other pines	NA	NA	NA	NA	NA
	Total	**300,000**	**300,000**	**380,000**	**5,500**	**11,000**
Utah	Lodgepole pine	36,880	50,420	127,310	231,920	220,929
	Ponderosa pine	11,745	11,650	21,520	57,980	55,200
	Other pines	0	0	0	0	0
	Total	**48,625**	**62,070**	**148,830**	**289,900**	**276,129**
Washington	Lodgepole pine	26,050	12,960	40,050	75,090	70,120
	Ponderosa pine	37,810	29,660	25,870	11,420	36,650
	Other pines	60,830	41,390	57,830	30,150	39,850
	Total	**124,690**	**84,010**	**123,750**	**116,660**	**146,620**
Wyoming	Lodgepole pine	150,000	160,000	170,000	145,000	163,000
	Ponderosa pine	25,000	25,000	35,000	55,000	50,000
	Other pines	0	0	0	0	0
	Total	**175,000**	**185,000**	**205,000**	**200,000**	**213,000**
Total		**4,397,901**	**4,687,890**	**4,710,461**	**4,217,409**	**3,575,238**

[1] NA = data not applicable. [2] — = data not available. [3] Entire area not flown.

Table 2. **Number of lodgepole pine, ponderosa pine, and other pines (sugar pine, western white pine, and whitebark pine) killed by the mountain pine beetle—from 1979 to 1983**

State	Tree species	1979	1980	1981	1982	1983
				Number of trees		
Arizona	Lodgepole pine	NA[1]	NA	NA	NA	NA
	Ponderosa pine	2,850	2,650	1,550	950	700
	Other pines	NA	NA	NA	NA	NA
	Total	**2,850**	**2,650**	**1,550**	**950**	**700**
California	Lodgepole pine	—[2]	—	—	—	10,000
	Ponderosa pine	138,715	59,300	—	—	—
	Other pines	—	—	—	—	—
	Total	**138,715**	**59,300**			**10,000**
Colorado	Lodgepole pine	12,000	25,000	75,000	450,000	786,500
	Ponderosa pine	423,500	92,000	55,000	15,000	8,500
	Other pines	0	0	0	0	0
	Total	**435,500**	**117,000**	**130,000**	**465,000**	**795,000**
Idaho	Lodgepole pine	671,765	4,241,033	839,075	313,549	87,477
	Ponderosa pine	11,474	20,994	2,310	4,582	6,371
	Other pines	147	3,856	879	704	109
	Total	**683,386**	**4,265,873**	**842,264**	**318,835**	**93,957**
Montana	Lodgepole pine	13,509,000	23,583,953	8,617,915	4,001,431	2,924,574
	Ponderosa pine	34,300	27,009	121,344	12,380	25,925
	Other pines	40,672	5,798	17,632	16,090	72,580
	Total	**13,583,972**	**23,616,760**	**8,756,891**	**4,029,901**	**3,023,079**
Nevada	Lodgepole pine	0	0	0	0	0
	Ponderosa pine	0	0	2,280	1,320	507
	Other pines	0	0	0	0	0
	Total	**0**	**0**	**2,280**	**1,320**	**507**
New Mexico	Lodgepole pine	0	0	0	0	0
	Ponderosa pine	3,550	1,500	4,900	1,700	850
	Other pines	0	0	0	0	0
	Total	**3,550**	**1,500**	**4,900**	**1,700**	**850**
Oregon	Lodgepole pine	1,339,705	1,109,442	972,854	1,390,015	3,815,047
	Ponderosa pine	380,402	122,242	45,655	39,002	215,819
	Other pines	5,710	2,012	460	640	35,665
	Total	**1,725,817**	**1,233,696**	**1,018,969**	**1,429,657**	**4,066,531**
South Dakota	Lodgepole pine	NA	NA	NA	NA	NA
	Ponderosa pine	80,000	70,000	50,000	12,000	5,100
	Other pines	NA	NA	NA	NA	NA
	Total	**80,000**	**70,000**	**50,000**	**12,000**	**5,100**
Utah	Lodgepole pine	49,340	78,340	340,525	3,468,700	1,256,577
	Ponderosa pine	14,006	22,400	19,500	87,000	91,961
	Other pines	0	0	0	0	0
	Total	**63,346**	**100,740**	**360,025**	**3,555,700**	**1,348,538**
Washington	Lodgepole pine	43,445	35,523	94,545	145,942	112,005
	Ponderosa pine	18,799	15,217	27,857	5,878	15,945
	Other pines	45,121	25,382	34,095	14,971	13,591
	Total	**107,365**	**76,122**	**156,497**	**166,791**	**141,541**
Wyoming	Lodgepole pine	93,500	140,560	230,835	451,400	461,707
	Ponderosa pine	147,000	280,000	330,000	355,000	12,000
	Other pines	0	0	0	0	0
	Total	**240,500**	**420,560**	**560,835**	**806,400**	**473,707**
Total		**17,065,001**	**29,964,201**	**11,884,211**	**10,788,254**	**9,959,510**

[1] NA = data not applicable. [2] — = data not available.

New and Innovative Management

Synthetic beetle attractants are now available to manipulate and monitor many small outbreaks (Borden and others 1983; Conn and others 1983). Baiting and trapping with attractants, managers can contain small spot infestations, thus preventing their spread into susceptible stands and maintaining beetle populations at low levels until roads can built, allowing for stand management. Using these new tools, managers can also protect high-value campgrounds and other recreation sites.

Partial cutting strategies (Cole and Cahill 1976; Cole and McGregor 1983; McGregor and others [in press]; Mitchell and others 1983), such as thinning of low- and moderate-hazard stands, have provided managers with additional options to reduce tree mortality from beetles, improve stand vigor, provide cover for wildlife, protect esthetics, prevent overcutting, maintain hydrologic requirements, and protect fisheries.

Outlook

The mountain pine beetle is the most destructive insect in western forests (fig. 7). Until inventories provide data to hazard rate stands and until roads permit access to high-hazard stands, outbreaks will continue and develop into epidemics.

In many areas, however, sanitation/salvage cutting, thinning of low- and moderate-hazard stands, and direct control have mitigated losses. These strategies, the synthetic beetle attractants, and the behavioral chemicals should provide managers with options to minimize future losses. As managers implement these options, the losses in valuable stands should begin to wane.

Table 3. **Management actions to salvage mortality and to prevent/suppress outbreaks—from 1979 to 1983[1]**

State	Area logged	Volume logged	Infested trees sprayed	Uninfested trees sprayed
	Acres	1,000 cubic feet	Number of trees	
Colorado:				
1979	5,855	59.0	87,000	0
1980	43,490	963.0	43,000	1,483
1981	37,550	1,217.0	2,000	6
1982	45,276	1,264.0	79,640	10,620
1983	15,570	991.0	52,586	674
Idaho:				
1979	10,162	61,399.9	0	3,200
1980	6,620	31,835.7	0	3,700
1981	7,972	42,248.4	0	435
1982	7,198	22,893.6	0	3,860
1983	10,908	37,681.6	0	333
Montana:				
1979	18,882	151,733.7	0	13,550
1980	20,586	135,342.0	0	550
1981	26,245	134,840.6	0	13,800
1982	24,806	99,569.9	0	0
1983	23,714	166,456.2	0	520
Nevada:				
1979	700	170.0	0	0
1980	700	170.0	0	0
1981	780	190.0	0	0
1982	960	220.0	0	0
1983	920	220.0	0	0
Oregon:				
1979	592	796.4	0	0
1980	596	801.9	0	0
1981	558	750.8	0	0
1982	323	435.6	0	0
1983	429	577.5	0	0
South Dakota:				
1979	120,678	12,360.0	0	0
1980	80,831	1,623.0	0	0
1981	253,158	123.0	0	0
1982	0	0	0	0
1983	0	0	0	0
Utah:				
1979	8,780	9,065.0	0	0
1980	11,868	12,523.0	0	0
1981	18,100	14,590.0	0	400
1982	10,465	9,558.0	0	200
1983	12,432	7,924.0	0	8,048
Washington:				
1979	49	65.5	0	0
1980	70	95.2	0	0
1981	74	100.1	0	0
1982	163	220.0	0	0
1983	163	220.0	0	0
Wyoming:				
1979	20,336	578.0	0	0
1980	1,430	883.0	0	0
1981	1,027	672.0	0	0
1982	6,715	1,206.0	0	0
1983	0	0	0	0
Total	**857,731**	**964,633.6**	**264,226**	**61,379**

[1]Arizona, California, and New Mexico conducted no beetle suppression during the 5-year period.

Seed Orchard Pests

Techniques and Timing as Flexible as the Pests

Written by Julie Weatherby

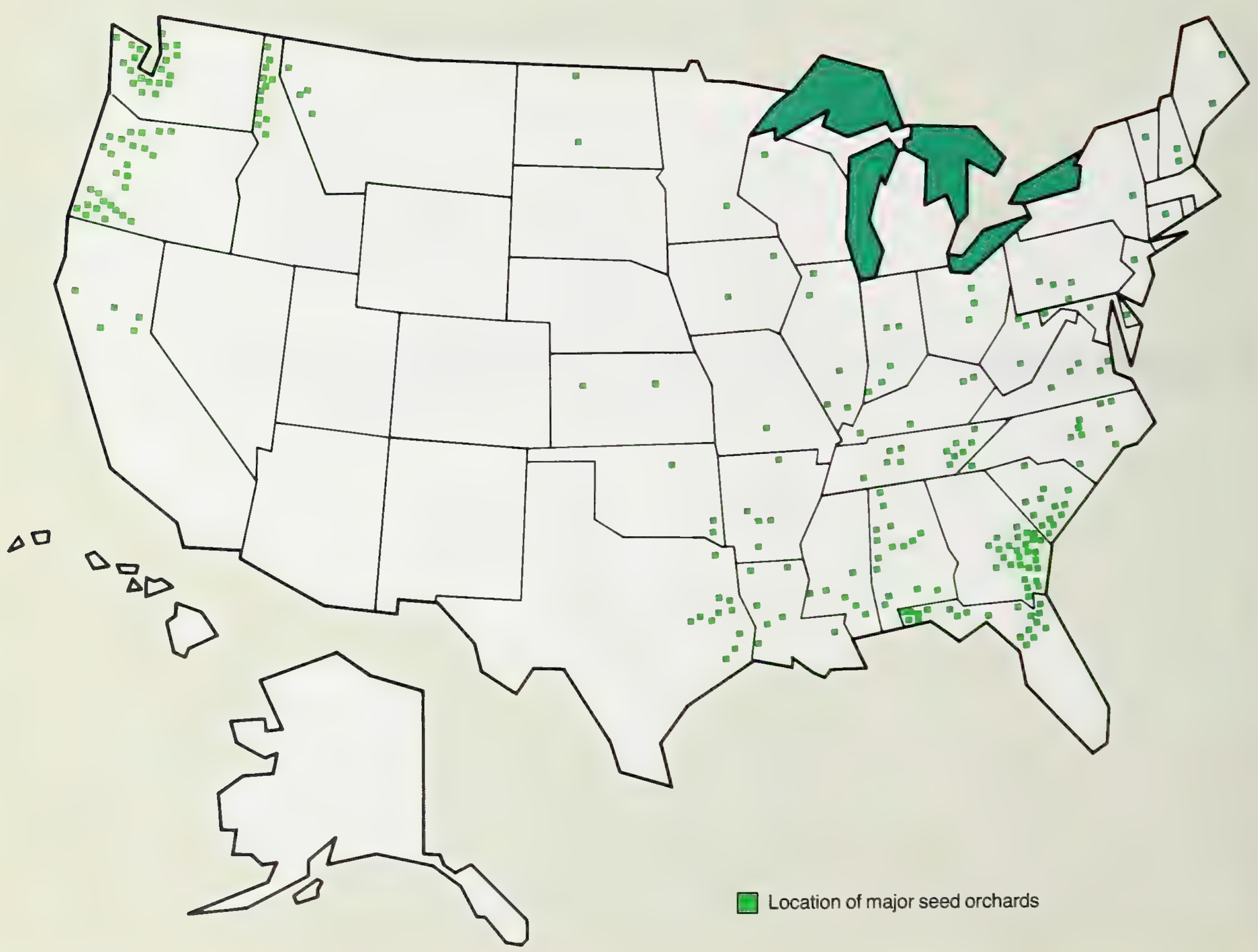
The forests we harvest today must be replaced to meet the projected resource needs of tomorrow. Tree planting is one way of replacing, or regenerating, forests. Planting genetically improved trees can boost wood production and quality, decrease rotation time, and reduce susceptibility to certain pests. These genetically improved trees are grown from seeds produced in seed orchards (fig. 1).

The first seed orchards were established from parents that grew in natural stands. The parents were selected because they grew fast, had good form, and were relatively free from pest damage.

The first operational pine seed orchards were established in the 1950's in the Southeast. By the late 1960's, seed orchards were being established throughout the major timber producing areas of the United States.

As orchards matured and seed production increased, it became necessary to protect both the

Figure 1. **Location of major seed orchards in 1983.**



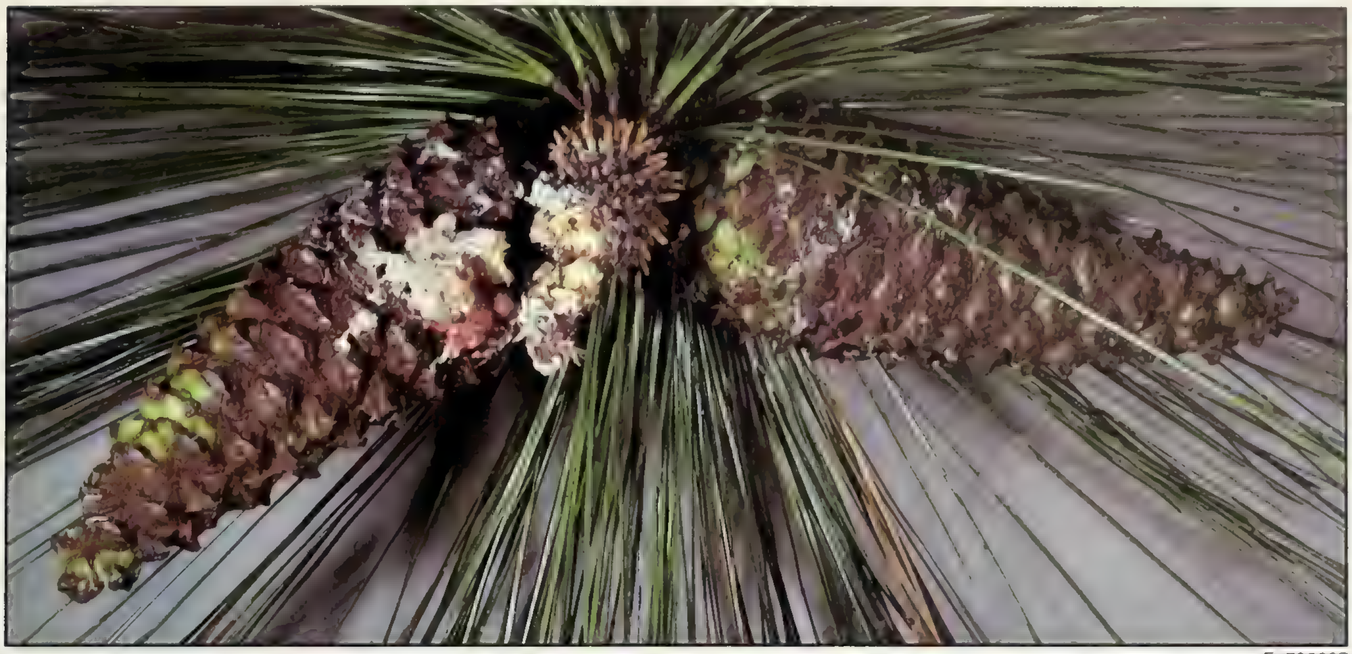


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Figure 2. Damaged cones. Several species of coneworms destroy cones, reducing the potential cone crops in seed orchards.

F-705638

Figure 3. Radiograph of full, empty, and seed bug-damaged seed.

Table 1. **Major insect pests that damage flowers, conelets, cones, and seeds in seed orchards in the United States**

Common name	Scientific name	Range	Host	Damaging stage	Structure damaged
Beetles:					
May beetle	*Phyllophaga micans* (Knoch)	East	Loblolly	Adult	Flowers
White pine cone beetle	*Conophthorus coniperda* (Schwarz)	Lake States, Northeast	Eastern white pine	Adult, larvae	Cones
Ponderosa pine cone beetle	*Conophthorus ponderosae* Hopkins	West	Western white pine, lodgepole, ponderosa, sugar	Adult, larvae	Cones
Flies:					
Douglas-fir cone gall midge	*Contarinia oregonensis* Foote	West	Douglas-fir	Larvae	Cones, seeds
Douglas-fir cone scale midge	*Contarinia washingtonensis* Johnson	West	Douglas-fir	Larvae	Cones, seeds
	Camptomyia pseudotsugae Hedlin and Johnson	West	Douglas-fir	Larvae	Cones, seeds
Southern pine scale midge	*Resseliella silvana* (Felt)	Southeast	Loblolly, longleaf, slash	Larvae	Cones
Pine pitch midge	*Cecidomyia piniinopis* Osten Sacken	Nationwide	Loblolly	Larvae	Conelets
Southern cone gall midge	*Cecidomyia bisetosa* Gagné	South	Slash	Larvae	Conelets
Fir cone maggot	*Hylemya abietis* Huckett	West	White fir, red fir	Larvae	Cones, seeds
Fir seed maggot	*Earomyia abietum* McAlpine	West	White, red, grand, Pacific silver fir	Larvae	Seeds
Moths:					
Pine conelet looper	*Nepytia semiclusaria* (Walker)	Southeast	Loblolly, sand, shortleaf, slash	Larvae	Flowers, conelets
Douglas-fir cone moth	*Barbara colfaxiana* (Kearfott)	West	Douglas-fir	Larvae	Cones
Shortleaf pine cone borer	*Eucosma cocana* Kearfott	Southeast, Middle Atlantic	Shortleaf, loblolly, Virginia	Larvae	Cones
Lodgepole pine cone borer	*Eucosma rescissoriana* Heinrich	West	Lodgepole, western white pine	Larvae	Cones
White pine cone borer	*Eucosma tocullionana* Heinrich	Northeast	Eastern white pine	Larvae	Cones
Slash pine seedworm	*Cydia anaranjada* (Miller)	Gulf Coast	Slash, loblolly, longleaf	Larvae	Seed
Longleaf pine seedworm	*Cydia ingens* (Heinrich)	Southeast	Longleaf, slash, loblolly	Larvae	Seed
Eastern pine seedworm	*Cydia toreuta* (Groté)	East	Jack, loblolly, lodgepole, red, shortleaf, Virginia	Larvae	Seed

Table 1. **Major insect pests that damage flowers, conelets, cones, and seeds in seed orchards in the United States—Cont.**

Common name	Scientific name	Range	Host	Damaging stage	Structure damaged
Moths (continued):					
Nantucket pine tip moth	*Rhyacionia frustrana* (Comstock)	East	Loblolly, shortleaf, ponderosa, lodgepole, Scotch, slash, Virginia	Larvae	Flowers
Fir coneworm	*Dioryctria abietivorella* (Grotė)	West, Northeast, Lake States	Pines, spruce, fir, Douglas-fir	Larvae	Cones
Ponderosa pine coneworm	*Dioryctria auranticella* (Grotė)	West	Ponderosa	Larvae	Cones
Southern pine coneworm	*Dioryctria amatella* (Hulst)	Southeast	Loblolly, longleaf, slash, shortleaf, Virginia	Larvae	Cones, flowers
Blister coneworm	*Dioryctria clarioralis* (Walker)	Southeast	Loblolly, longleaf, shortleaf, slash	Larvae	Cones, conelets, flowers
Webbing coneworm	*Dioryctria disclusa* Heinrich	East	Loblolly, longleaf, shortleaf, Virginia, red, Scotch, jack	Larvae	Cones
Loblolly pine coneworm	*Dioryctria merkeli* Mutuura and Munroe	Southeast	Loblolly, longleaf, shortleaf, slash, Virginia	Larvae	Cones
Spruce budworm	*Choristoneura fumiferana* (Clemens)	Northeast, Lake States	Balsam fir, larch, hemlock, spruce	Larvae	Cones, flowers
Western spruce budworm	*Choristoneura occidentalis* Freeman	West	Douglas-fir, grand fir, western larch	Larvae	Cones, flowers
Wasps:					
Douglas-fir seed chalcid	*Megastigmus spermotrophus* Wachtl	West	Douglas-fir	Larvae	Seed
Thrips:					
Slash pine flower thrips	*Gnophothrips fuscus* (Morgan)	Gulf Coast	Slash	Adult, larvae	Flowers
True bugs:					
Leaffooted pine seed bug	*Leptoglossus corculus* (Say)	Southeast, Middle Atlantic	Southern pines	Adult, nymph	Conelets, seeds
Western conifer seed bug	*Leptoglossus occidentalis* Heidemann	West	Western pines	Adult, nymph	Conelets, seeds
Shieldbacked pine seed bug	*Tetyra bipunctata* (Herrich-Schaffer)	East	Eastern pines	Adult, nymph	Conelets, seeds

Table 2. **Major diseases affecting seed orchards in the United States**

Common name	Scientific name	Range	Host	Structure affected
Pitch canker	*Fusarium monoliforme* var. *subglutinans* Wr. & Reink.	Southeast	Southern pines	Stem, branches
Fusiform rust	*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme*	Southeast	Slash, loblolly	Stem, branches
Annosus root disease	*Heterobasidion annosum* (Fr.) Bref.	Southeast	Southern pines	Roots
Cone rust	*Cronartium* strobilinum Hedgc. & Hahn	Florida, Georgia	Slash, longleaf	Cones

valuable trees and their crops from insects and diseases. Even under current management programs, insects and diseases often destroy more than 50 percent of the cone and seed crops.

Table 1 lists the major insects causing direct damage to cone (fig. 2) and seed (fig. 3) crops. In addition to these pests, several others cause indirect damage to cone crops by damaging shoots, needles, branches, and boles.

Diseases that are commonly found in seed orchards reduce cone and seed crops by affecting cones and seeds directly, by causing dieback within productive portions of the crown, by stressing trees and thus predisposing them to other pests, or by causing tree mortality. Table 2 lists the major seed orchard diseases.

Historical Perspective

Before the establishment of seed orchards, cone and seed insects caused moderate losses in natural seed production areas. Without suppression efforts, pest populations fluctuated under the control of predators, parasites, and environmental pressures. When the first southern pine seed orchards began producing in the 1960's, it became apparent that natural forces would not adequately protect seed crops and that intensive management would change the relative importance of many natural pests. Research was begun to identify the most serious pests, quantify impact, and develop management strategies.

Resources Affected

Existing seed orchards are unable to produce enough improved seed to meet the needs of future forest regeneration plans. Losses to insects and diseases further reduce the usable supply of seed. If adequate supplies of improved stock are not available, stands will have to be regenerated with general forest stock. Such a practice is expected to decrease volumes by 10 to 20 percent.

Pest Status From 1979 to 1983

Approximately 80 percent of the total acreage of established seed orchards in the United States is located in the Southeast from Texas to Virginia. Because of the magnitude and age of the southern tree improvement program, this area experiences the greatest loss from pest outbreaks. Insect-caused losses were high in 1979, when approximately 83,280 pounds of seed from all southern pine sources were destroyed by insects (table 3). The most significant losses were attributed to the leaffooted and shieldbacked pine seed bugs and the webbing coneworm in the southern coastal States.

Although the total losses across the Southeast declined in 1980, certain severely damaged seed orchards lost up to 90 percent of their crop to the webbing coneworm. Improvements in the timing of pesticide applications during 1981 resulted in good con-

trol of webbing coneworm populations; however, moderate losses, 26,320 pounds of seed, were attributed to the loblolly pine coneworm, the blister coneworm, the southern pine coneworm, the leaffooted pine seed bug, and the shieldbacked pine seed bug. Seed losses were low in 1982: 17,050 pounds of seed were lost. Excellent cone survival and decreased pest population pressures resulted in moderate to good crops in 1983.

Very little disease impact information is available for seed orchards. Isolated outbreaks of pitch canker have caused dieback throughout certain orchards. One shortleaf pine seed orchard had more than 99 percent of its trees infected. Fusiform rust is a particularly severe problem in certain slash and loblolly orchards. Bole cankers and associated coneworm tunneling weaken the main stems, and the stem breaks at the canker. Fusiform rust has played a major role in determining priorities for roguing activities in many slash pine orchards. Clones showing susceptibility to fusiform rust are removed from the orchard. Root rots have not had significant impact because of precautionary practices. Cone rust continues to reduce cone crops in slash pine orchards in Florida and southern Georgia. Many slash pine seed orchard managers in this area are encouraged to routinely spray with fungicides to prevent cone rust disease.

Seed orchards established in Washington and Oregon account for approximately 10 percent of the total seed orchard acreage in the United States. Many of the 47 orchards within this region are not old enough to produce seeds. As these orchards mature, seed production and pest impacts will increase. Where seeds were produced, insect pests destroyed between 10 to 20 percent of the crop in 1979 and 1 to 10 percent of the crop in 1980. Because production levels were low, these losses were not significant. In 1981, insects destroyed approximately 140 pounds of seed; in 1982, losses attributed to insects declined from the 1981 level. Only a slight increase was detected in 1983.

Idaho and Montana have 18 seed orchards, accounting for approximately 2 percent of the total seed orchard acreage in the United States. These orchards contain plantings of Douglas-fir, grand fir, western larch, ponderosa pine, and western white pine. Only three western white pine orchards are in production. Ponderosa pine cone

***Table 3.* Seed orchard losses in pounds of seed caused by major insect pests from 1979 to 1983**[1]

State	Host	1979	1980	Annual losses 1981	1982	1983
				Pounds of seed		
Alabama	Southern pines	7,460	1,780	2,360	1,530	870
Arkansas	Southern pines	4,150	990	1,310	850	480
California	Douglas-fir, ponderosa pine, white and red fir, sugar pine	NA[2]	10	20	NA	22
Florida	Southern pines	17,410	4,150	5,500	3,560	2,020
Georgia	Southern pines	11,610	2,770	3,670	2,370	1,350
Idaho	Western white pine	0	15	14	10	20
Kentucky	Southern pines	360	90	110	70	40
Louisiana	Southern pines	8,290	1,980	2,620	1,700	960
Mississippi	Southern pines	5,800	1,390	1,840	1,190	670
Montana	Western white pine	0	15	14	10	20
North Carolina	Eastern white pine	6,630	1,580	2,100	1,360	770
Oklahoma	Southern pines	1,660	400	520	340	190
Oregon	Douglas-fir	4	1	70	8	40
South Carolina	Southern pines	6,630	1,580	2,100	1,360	770
Tennessee	Southern pines	3,320	790	1,050	680	390
Texas	Southern pines	4,980	1,190	1,570	1,020	580
Virginia	Southern pines	4,980	1,190	1,570	1,020	580
Washington	Douglas-fir	4	1	70	8	40
Total		**83,288**	**19,922**	**26,508**	**17,086**	**9,812**

[1]Data for Northeast incomplete—orchards not included in table.
[2]NA = Not available.

Figure 4. **Helicopter applying insecticide to a seed orchard in Brooksville, FL.**

F-705639

beetles damaged more than 20 percent of the white pine cone crop in 1979. In 1980, this pest destroyed less than 10 percent of the cone crop, or approximately 28 pounds of seed. Approximately 29, 17, and 35 pounds of seed were lost because of cone beetle feeding in 1981, 1982, and 1983, respectively. As production increased during this 5-year period, 10 to 20 percent of the loss was attributed to the lodgepole pine cone borer and the fir coneworm; more than 10 percent of the loss was caused by the western conifer seed bug.

California has 206 acres of seed orchards under Federal and State ownership. These orchards make up approximately 2 percent of the total seed orchard acreage in the United States. Federal orchard plantings of ponderosa pine, Douglas-fir, and rust resistant sugar pine are just beginning to produce crops. Coneworm species are currently the key pests in the Sierra Mountains, whereas the Douglas-fir cone moth and the cone gall midge cause the greatest losses of Douglas-fir seed along the coast and in the Siskiyou Mountains. Current evidence suggests that the western conifer seed bug and the ponderosa pine cone beetle have the potential to become localized problems.

In 1979, approximately 15 percent of the potential seed crop was destroyed by the Douglas-fir cone moth, the Douglas-fir cone gall midge, and the fir coneworm. Again in 1980, these pests accounted for most of the damage. In addition to the previously mentioned pests, populations of seed chalcids, ponderosa pine coneworms, and fir cone maggots infested the small 1981 cone crop and destroyed more than 20 percent of the potential crop. The Douglas-fir cone crop was large in 1982, and insect populations caused very little damage. In 1983, a light cone crop year, insect populations rebounded and caused 10 to 20 percent reduction in potential production.

Seed orchards in the Northeast are just being established and account for approximately 1 percent of the total seed orchard acreage in the United States. The white

pine cone beetle causes the greatest economic losses within this region.

Prevention/Suppression

In areas where seed orchards are beginning to produce, the pest management strategy to suppress insect populations emphasizes sanitation practices, such as removal of all infested cones. This strategy may prevent pest population buildup in orchards. However, in orchards where pest immigration into the orchard is likely, such a strategy does not provide adequate protection. In mature, producing orchards, the pest management strategy usually consists of an insecticide spray schedule.

Several chemicals are currently registered for application on seed orchards. Before 1982, these insecticides were applied as liquids with a hydraulic or airblast sprayer or as granulars with a power-till seeder. Today, more and more southern pine seed orchards are being sprayed with fixed-wing or rotary-wing aircraft (fig. 4). Aerial applications deposit more insecticide into the cone-bearing upper portion of the crown. It has thus been possible to reduce the amount of insecticide applied per acre by more than 50 percent. Orchard pest management strategies for the future will emphasize a flexible spray schedule that responds to specific pest conditions. Emphasis will be on monitoring pest populations in order to determine when applications are needed and to time applications for maximum effectiveness.

The prevention of disease epidemics is an important consideration in the pest management programs for seed orchards. In general, sanitation practices and proper wound treatment have minimized the impact caused by diseases. Pruning and removal of infected material may help remove sources of inocula. On certain sandy soil types, subsoiling and insecticide applications with the power-till seeder are not recommended because of root disease hazard. Stump treatment with borax to prevent the establishment of annosus root disease is included in most roguing operations. Future pest management programs will require an increased understanding of pathogens and environmental interactions that lead to disease outbreaks. Individual orchards will be hazard rated for pest problems to identify—and avoid—cultural practices that may encourage disease establishment.

Outlook

Pest population outbreaks and disease epidemics in seed orchards will continue to cause unacceptable losses, and the use of pesticides will remain a critical part of pest management programs. Improvements in insect population monitoring will help determine when insecticide applications are needed and when those applications will be most effective. As these techniques become operational, orchard managers will move away from fixed spray schedules, relying on flexible schedules designed to reflect current conditions within individual orchards.

A Would-Be Manager of Southern Forests

Written by William H. Hoffard

The southern pine beetle has earned its reputation as a "manager" of pine forests in the South.

Smaller than most grains of rice, these dark, hard-bodied insects (fig. 1) attack *en masse* directly through the tree bark. This aggregating behavior often overcomes—and kills—the tree. As the adults breed and then move to nearby trees, the infestation center, or spot, expands to include more and more trees (fig. 2). Populations can build rapidly: left unchecked, individual spots can grow to involve thousands of trees within a few weeks.

Photo courtesy of Thomas Payne, Texas A&M University

Figure 1. **Micrograph photograph of southern pine beetle.**

The beetle attacks all southern yellow pines. Shortleaf and loblolly pines are principal hosts; slash and Virginia pines are also susceptible. The very resinous condition of longleaf pine makes it somewhat resistant to mass attacks. Eastern white pine growing in the southern mountains is often infested.

F–705640

Figure 2. **Discolored foliage marks an infested spot in Oconee National Forest, GA.**

Although the natural range of the southern pine beetle in the United States extends north into Missouri, Illinois, Indiana, Ohio, Pennsylvania, New Jersey, Delaware, and Maryland (fig. 3), it is economically important only south of the Ozark Mountains and the Ohio River. A separate population in Arizona is of little economic importance.

Population levels are cyclic and vary considerably. From year to year, the area infested may range from more than 10 million acres (4 million ha) to less than 1 million acres (0.4 million ha). Typically, outbreak acreage drops dramatically after 3 or more years of high activity. Nonetheless, the

South is never completely free of outbreak areas.

Historical Perspective

As early as the late 1700's, several writers documented what entomologists consider widespread mortality caused by southern pine beetle. Long before formal records of its damage were kept, accounts suggest that the southern pine beetle was causing heavy losses in North Carolina during the 1750's and that, around 1800, a widespread outbreak occurred from the Appalachians through the Coastal Plain.

After the Civil War, many cotton fields reverted to, or were planted with, pine. This sharp increase in host acreage increased the significance of the beetle. Sketchy data indicate that 12 to 15 outbreaks occurred from 1882 to 1960.

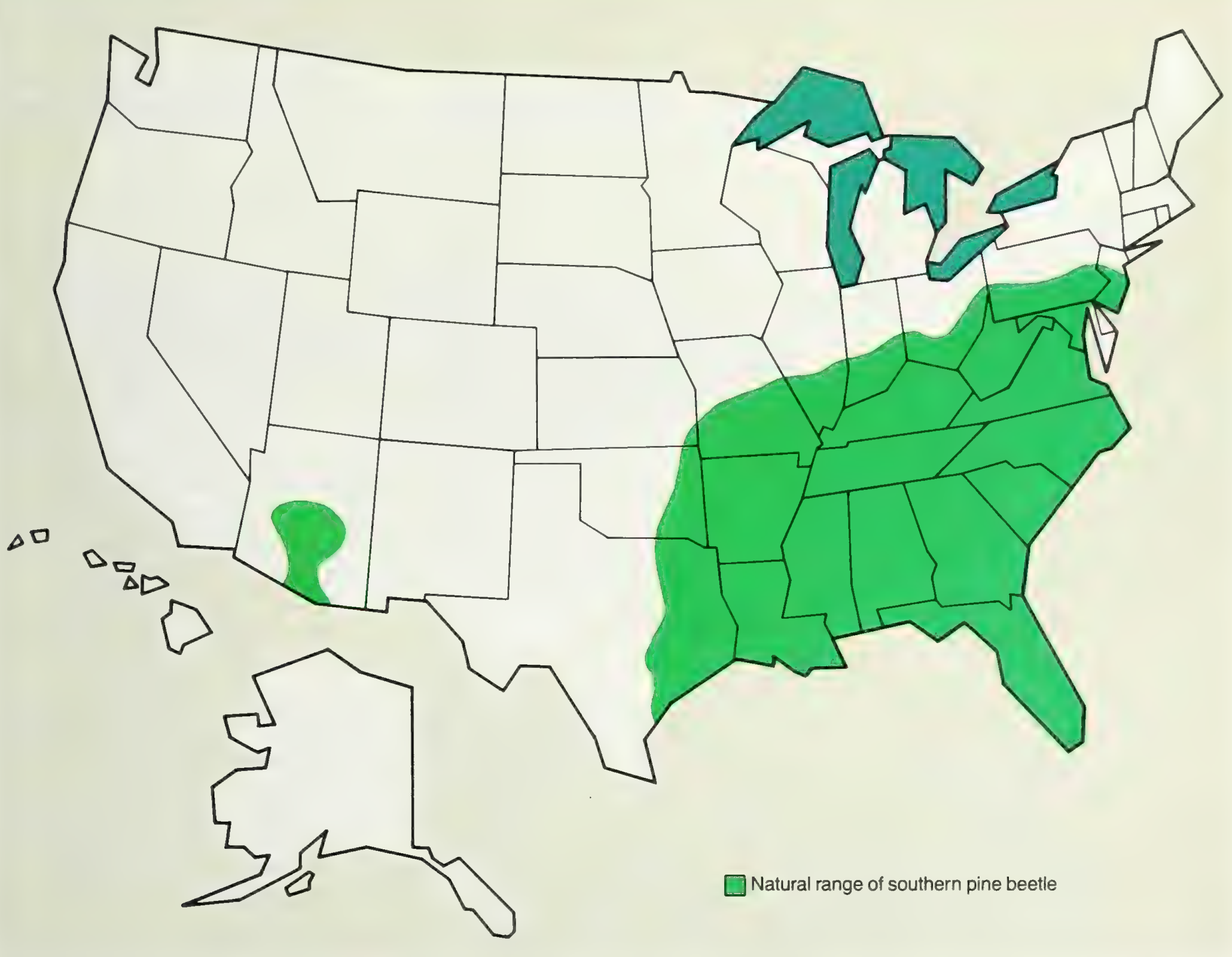
Since 1960, improved survey techniques have produced far more reliable statistics on the numerous local outbreaks that have occurred. These local outbreaks culminated in a widespread epidemic lasting from 1971 to 1976. Another outbreak began in 1978.

Resources Affected

Although its most noteworthy impact is on timber, the southern pine beetle also affects virtually all other resources. Campgrounds consisting predominantly of pine trees have been ruined. In towns and cities, thousands of valuable shade trees have been killed. The esthetic impact can be dramatic, particularly in the mountains, where large areas of dead trees are easily visible.

The effects on the wildlife resource vary. Beetle-caused mortality can actually benefit deer and some birds by opening forest canopies, thus encouraging the growth of sun-loving ground cover. However, in some areas, the southern pine beetle competes with the endangered red cock-

Figure 3. **The natural range of southern pine beetle in the United States.**



aded woodpecker for old, heartrot-infected trees. This competition not only reduces bird habitat but also complicates control efforts.

Status From 1979 to 1983

The epidemic that began in 1978 persisted until 1981, when it collapsed (fig. 4). At its peak, this epidemic covered 15 million acres (6.1 million ha) of host type. Most of the outbreak areas were in four States: Alabama, Georgia, South Carolina, and Mississippi. Texas and Louisiana, two States that had suffered heavy losses in earlier outbreaks, were not part of the severely infested area.

The bulk of the losses from 1979 to 1983 occurred in the Piedmont (fig. 5)—a fact perhaps explained by unusually dry conditions in this area. Drought may have reduced the trees' resistance to the mass attacks of the southern pine beetle. By contrast, the Western Gulf States, which had relatively abundant rainfall, were not severely infested (Anderson and Hoffard 1982).

Table 1 lists the acreage infested each year by State. These acreage figures represent the total

***Figure 4.* Area infested by southern pine beetle by year from 1979 to 1983.**

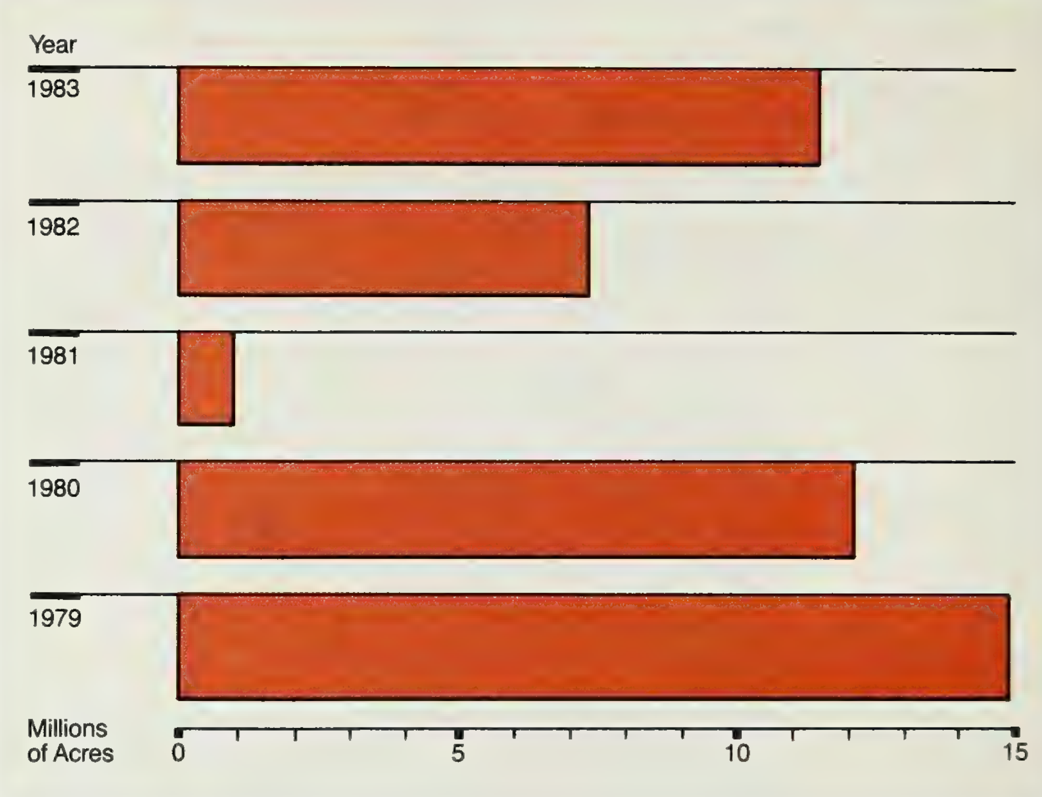
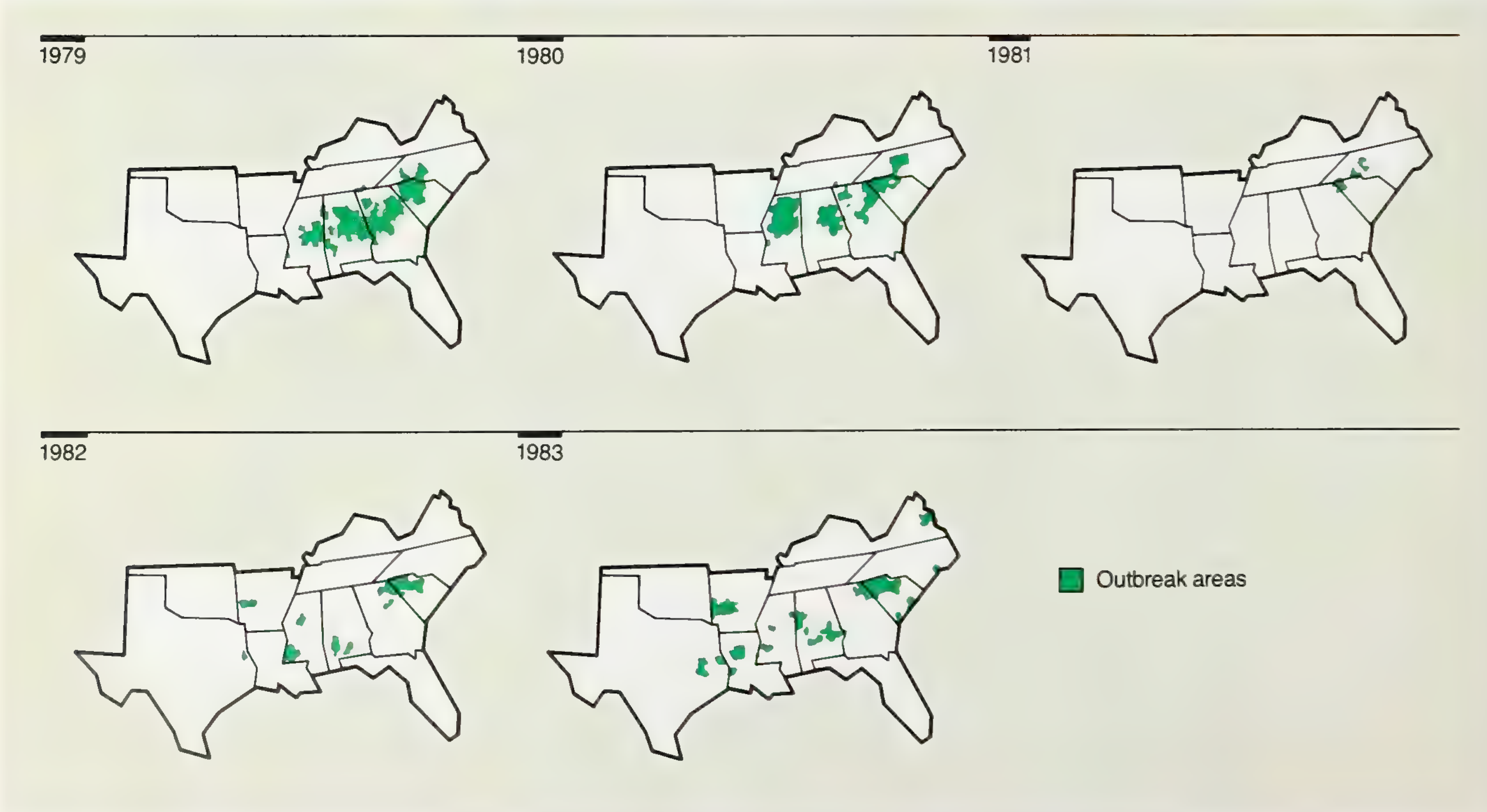


***Figure 5.* Areas of southern pine beetle outbreaks from 1979 to 1983.**



host type in "outbreak counties," that is, counties containing one or more multiple-tree spots per 1,000 acres (405 ha) of susceptible host forest.

The volume of timber killed in 1979–83 totaled about 614.5 million cubic feet (17.4 million m^3) (table 2). Table 2 contains volumes only for the States that have outbreak counties listed in table 1. Thus, for example, although North Carolina doubtless lost some trees to southern pine beetle in 1982, no volumes are included for that State for 1982 because no outbreak counties were reported that year.

Figure 6 compares the volume of pulpwood lost in 1979–83 with the volume of sawtimber lost. These data reflect product more than they reflect tree size: during the economic recession of 1979–82, many sawlog-sized trees were processed into pulp because of poor sawlog markets. In all, an estimated 368.7 million cubic feet (10.4 million m^3) was salvaged during the 5-year period.

Table 1. **Acres of southern pine beetle outbreaks by State from 1979 to 1983**[1]

State	1979	1980	1981	1982	1983	Total
			1,000 acres			
Alabama	5,156.6	2,227.8	0	1,388.2	1,880.1	10,652.7
Arkansas	0	0	0	830.0	2,817.6	3,647.6
Georgia	4,574.8	2,498.5	22.0	720.5	774.8	8,590.6
Louisiana	0	0	0	123.6	248.4	372.0
Mississippi	1,324.2	2,408.4	0	1,106.3	452.6	5,291.5
North Carolina	386.3	1,539.0	236.0	0	81.8	2,243.1
South Carolina	3,389.7	3,367.0	606.4	2,924.2	3,190.0	13,477.3
Tennessee	134.4	84.0	0	0	0	218.4
Texas	0	0	0	234.7	1,220.4	1,455.1
Virginia	0	0	0	0	740.3	740.3
Total	**14,966.0**	**12,124.7**	**864.4**	**7,327.5**	**11,406.0**	**46,688.6**

[1]Acres of host type in counties having one or more multiple-tree spots per 1,000 acres (405 ha).

Table 2. **Estimates of cubic feet of timber killed by southern pine beetle in States with outbreak counties from 1979 to 1983**

State	1979	1980	1981	1982	1983	Total
			1,000 cubic feet			
Alabama	85,010	92,325	0	22,236	33,396	232,967
Arkansas	0	0	0	10,448	14,808	25,256
Georgia	65,031	59,175	221	13,496	16,332	154,255
Louisiana	0	0	0	5,768	11,497	17,265
Mississippi	14,351	32,997	0	17,182	7,860	72,390
North Carolina	11,784	30,805	87	0	1,822	44,498
South Carolina	8,522	20,198	8,028	2,721	8,057	47,526
Tennessee	40	454	0	0	0	494
Texas	0	0	0	2,358	10,080	12,438
Virginia	0	0	0	0	7,373	7,373
Total	**184,738**	**235,954**	**8,336**	**74,209**	**111,225**	**614,462**

Prevention/Suppression

Significant developments in the management of the southern pine beetle have occurred during the past 5 years. Many of the new approaches have come from research funded by two U.S. Department of Agriculture-sponsored programs: the Expanded Southern Pine Beetle Research and Applications Program and the Integrated Pest Management Program (Thatcher and others 1981). These new developments can generally be classed as detection, evaluation, control, or integrated pest management, which includes elements of the first three categories. All four categories are discussed in detail (Hoffard 1982).

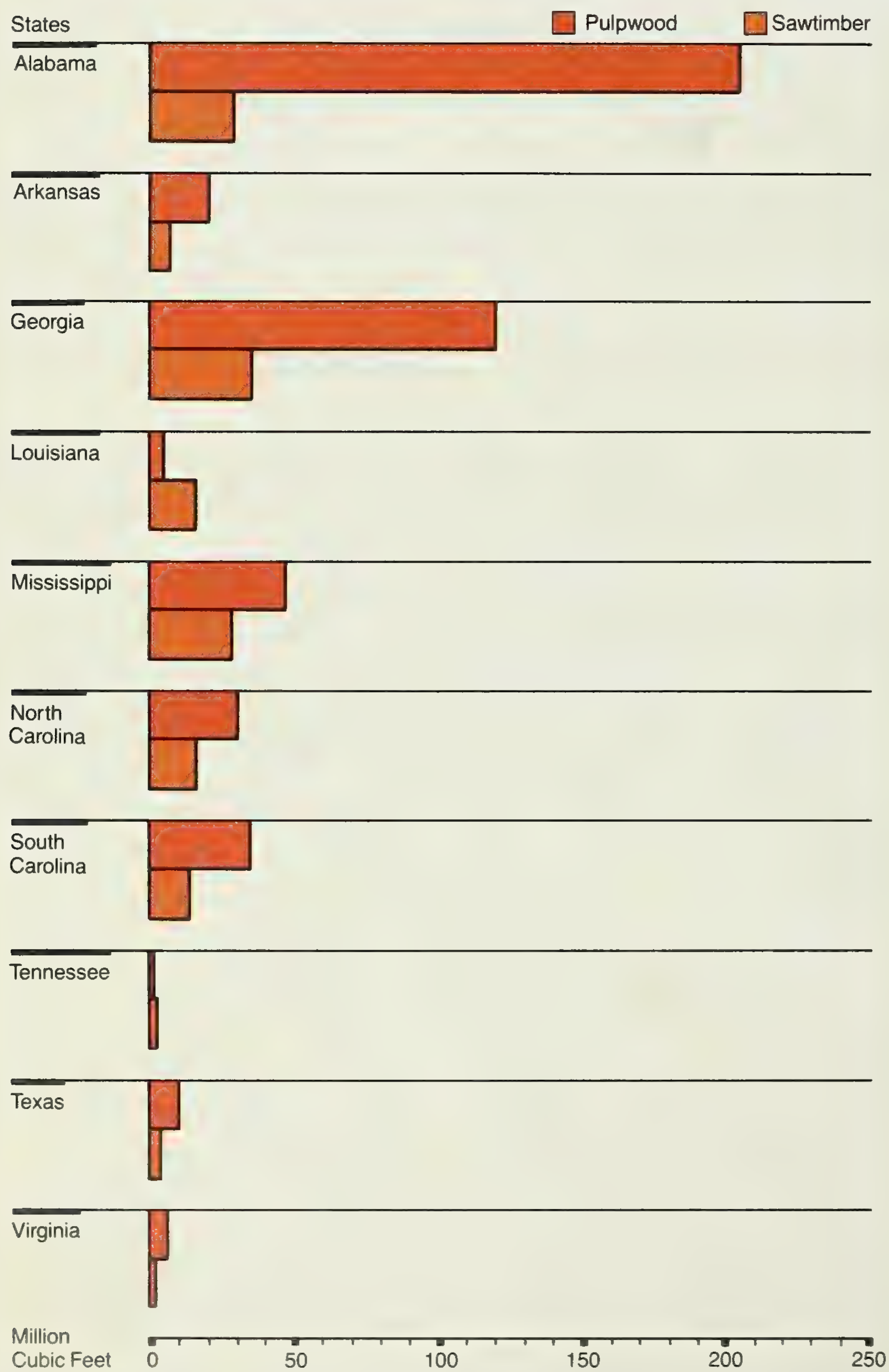
Detection. Perhaps the most significant development in the category of detection has been the use of Loran-C when doing aerial surveys. This long-range aid to navigation, developed by the U.S. Coast Guard, uses radio signal triangulation to pinpoint location. The pilots of aircraft equipped with Loran-C can fly with more precision, thereby increasing detection accuracy (Dull 1980) (fig. 7). Other benefits are significant reductions in fuel, equipment, and time.

Evaluation. Researchers have developed a variety of region-specific hazard-rating systems to predict a stand's susceptibility to beetle attack (fig. 8). Foresters can use such systems to determine if

stands need preventive treatment or increased surveillance. These hazard-rating systems may use existing computer-based data or information readily gathered in the field.

A second development involves setting control priorities once beetles have attacked. Researchers have identified and weighed several variables that help determine which spots to consider treating first. These variables include the presence of trees that have been recently attacked, the number of trees hosting certain life stages, and the stand basal area. Once they have weighed these variables, land managers can use a simple numerical system to determine which spots are most likely to spread. They can then act accordingly.

***Figure 6.* Estimated volume killed by southern pine beetle by State from 1979 to 1983.**



Control. The cut-and-leave technique has been proved effective for spots of 10 to 50 trees. Infested trees are felled toward the center of the spot. A buffer strip of uninfested trees at the spreading edge is also felled. If managers apply this method when spots are expanding (May through October), they can halt the spread of an infestation. This technique is quick, simple, inexpensive, and requires a minimum of manpower and equipment. It is particularly valuable during outbreak conditions when time-consuming salvage work can slow the overall progress of the control project.

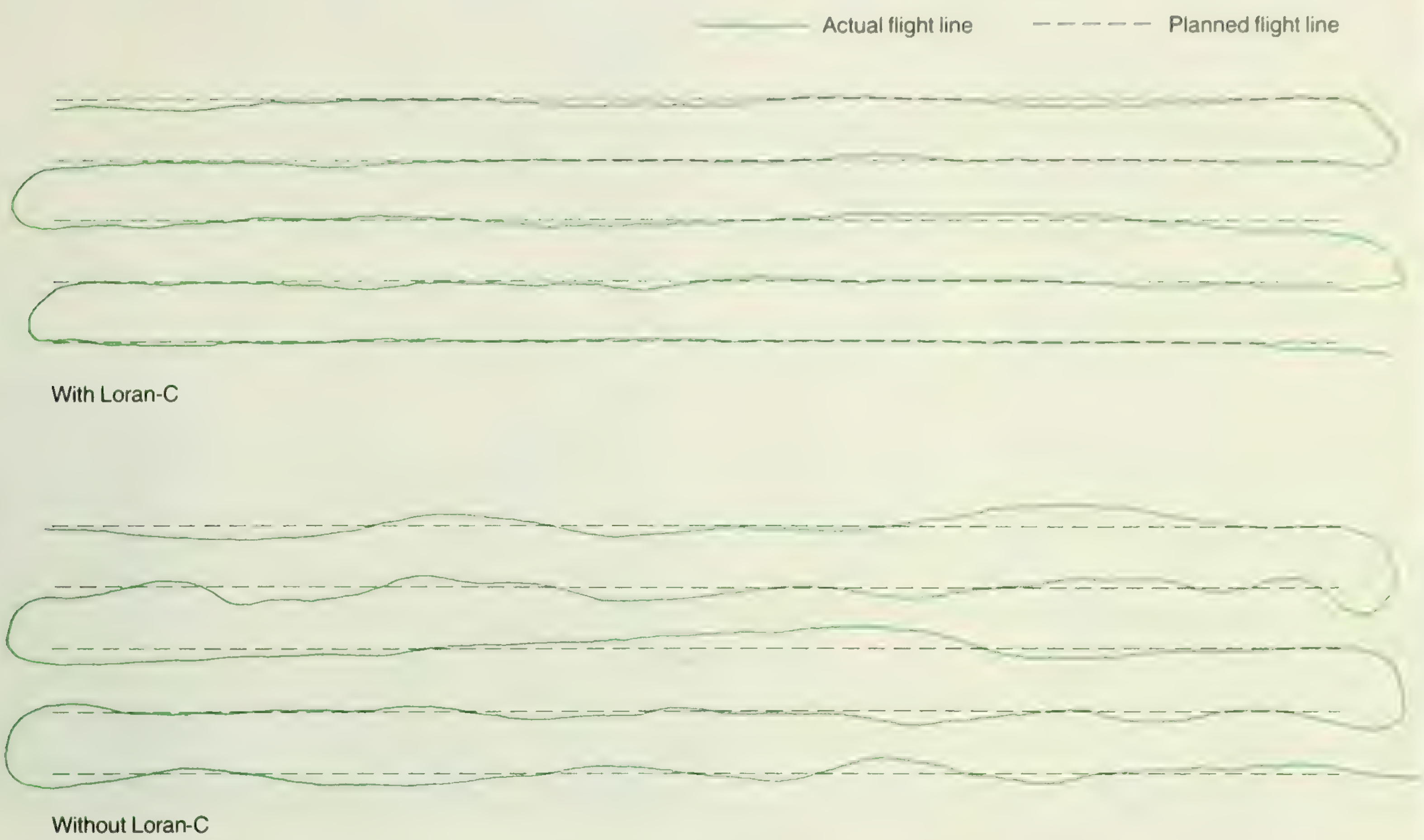
In addition to lindane, another insecticide, chlorpyrifos, has been registered for use against the southern pine beetle. As a result, land managers now have more latitude in tailoring an insecticide program to meet their budgets and needs.

Integrated Pest Management. The management of host and environmental factors, coupled with accurate prediction systems, will enable resource managers to sidestep many beetle problems before they develop (Knight 1981).

Managers now have computerized systems to help them make decisions about the resource. One such system, a program developed by Texas A&M University, analyzes the problems involved in making decisions on southern pine beetle management. This computerized program can, for example, refer the user to an empirical system, such as one that projects severity of losses in different situations.

Another computerized system, the Integrated Pest Management

Figure 7. **An aerial survey crew's ability to conform to survey lines with and without Loran-C.**



Decision Key, developed by the USDA Forest Service (Anderson and others 1983), considers variables, such as environment, economics, geographic location, and pest interaction, and then formulates management options for various scenarios. One advantage of this system is the ease with which it can be expanded or modified to include new technology—a more cost-effective approach than the publication of research results.

Outlook

The widely dispersed outbreak areas of 1983 were typical of an incipient outbreak, and most entomologists feel that beetle losses will increase throughout the Western Gulf States. Actual losses, however, will depend on winter temperatures and rainfall amounts.

Resource managers are now better prepared than ever to deal with the southern pine beetle: detection, evaluation, and control techniques are all improving. Managers no longer think of the southern pine beetle as "just an insect problem." Over the long run, losses can be reduced only through improved forest management. Such practices include reducing the length of the rotation, thereby eliminating older, more susceptible timber, and planting trees suitable to the site. Managers will have to practice integrated pest management—management that is effective yet environmentally and economically responsible—if they hope to reduce southern pine beetle-caused losses.


F–705641

Figure 8. **Rating a stand in Croatan National Forest in North Carolina. A prism is used to determine basal area—the area of the cross section of a tree stem at beast height. Basal area is one of the factors considered in several risk-rating systems.**

Once Again, the Budworm Is Killing Our Aging Forests

Written by Daniel R. Kucera

Over 150 million acres (61 million ha) of spruce and fir trees cover the North American continent from Manitoba and Newfoundland, Canada, south to Minnesota and Nova Scotia. The portion within the United States, roughly 12 million acres (5 million ha), lies at the southern tip of this vast area (Kettela 1983).

These immense forests of spruce and balsam fir contain an insect called the spruce budworm. From 1979 to 1983 defoliation in the United States caused by the spruce budworm averaged more than 4 million acres (1.6 million ha) per year (fig. 1).

The spruce budworm has four life stages. Adult spruce budworms are grayish moths that have mottled dark-brown markings. They are strong flyers. Moths can fly about 50 miles a day and may eventually travel hundreds of miles. They move around the upper canopy in quick, jerky motions, looking for needles on which to lay their eggs (figs. 2 and 3). Budworm larvae, which emerge from the eggs, first attack the new buds and then the new needles. When fully grown, the larvae spin a loose web around themselves and pupate. After a couple of weeks, the adult moths emerge.

Large, outbreak-sized populations generally develop in extensive and continuous areas of mature and overmature balsam fir—the preferred host of the spruce budworm. In the mid-1970's, more than 60 percent of the eastern spruce-fir was mature or overmature. The subsequent epidemic peaked in 1978. But the 2- to 5-year time lag between severe defoliation and resultant tree mortality means that losses attributed to that outbreak continued through 1983.

Historical Perspective

The first outbreak recorded in the United States occurred in Maine about 1807. Another outbreak followed in 1878. At the turn of the century, the first estimates of volume loss were recorded: from 1910 to 1918, more than 27 million cords (65.1 million m^3) of spruce and fir were destroyed in Maine. Since 1909, waves of outbreaks have been recorded in the Eastern United States and Canada. The States most often affected are Maine, New Hampshire, Vermont, Michigan, Minnesota, and Wisconsin.

By the mid-1970's, more than 60 percent of the eastern spruce-fir forests had reached the mature or overmature stage, and this large area of susceptible hosts provided a huge source of the budworm's preferred foods: buds, male flowers, and foliage from mature or overmature trees. The outbreak, which began in the mid-1970's, peaked in 1978.

The increasing demand for spruce-fir sawtimber and pulpwood during the past 10 years and the resultant mill expansion have fostered a concern for both protecting and managing mature stands until they can be replaced by younger forests.

Managers in the Lake States and in New England are also planting superior stock to replace those old-growth stands. The stock comes from seed orchards,

Figure 1. **Acres defoliated by spruce budworm.**

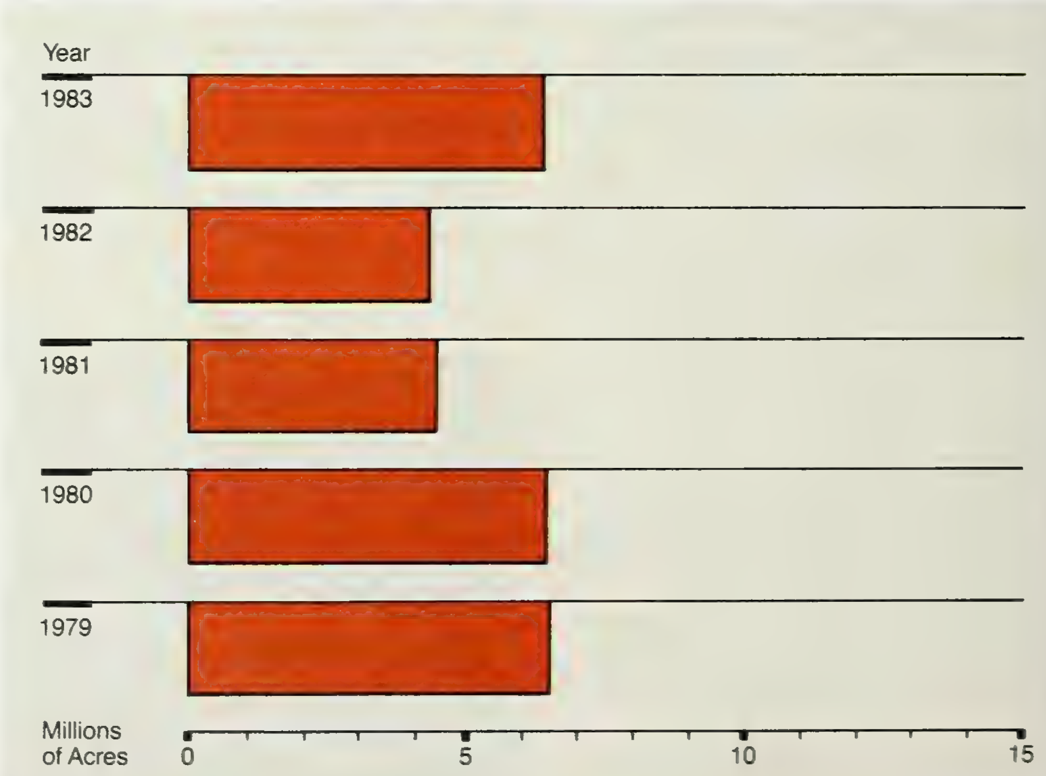


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Figure 2. **Larvae emerging from egg mass on balsam fir needle.**

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Figure 3. **Egg mass on a balsam fir needle magnified by an electron micrograph.**

such as the Great Northern Paper Company's orchard in Millinocket, ME. In 1985, more than 300 million seedlings may be planted in eastern Canada alone.

Resources Affected

Timber. Defoliation weakens trees, causing growth loss and, at times, mortality. Hemlock, for example, may die after only one heavy defoliation.

During epidemics, a variety of conifers, as well as white, red, and black spruces, are attacked by the larvae. Spruces are more susceptible when they grow mixed with balsam fir. Hemlock and, to a lesser extent, tamarack and pine may also be attacked. During the outbreak that began in the Lake States in 1979, balsam fir and then white spruce were most affected. No damage was recorded on black spruce. In New England, balsam fir, red spruce, and, to a lesser extent, white spruce were defoliated.

Other Resources. Little is known about how other resources are affected by the spruce budworm; however, information has recently been collected on how defoliation affects wildlife, such as deer. During the winter months, deer seek shelter in dense stands of mature spruce and fir, known as deer yards. When budworms defoliate these stands, the deer lose their shelter. Many deer may die. Consequently, some landowners are now spraying these yards to protect the deer by protecting the trees. Along the border with Canada, moose yards are also being sprayed to improve moose habitat.

Furthermore, defoliation temporarily exposes brooks and ponds to the rays of the sun, thereby raising the water temperature. This indirectly affects

anadromous fish, such as salmon and trout, that require cool water when they swim upstream to spawn.

The impact of defoliation on recreation is not as great as on other resources: there are few campgrounds and picnic areas in spruce-fir stands. More often, recreation areas are in hardwood stands.

Trend From 1979 to 1983

Defoliation has fallen since the current outbreak peaked at 7.7 million acres (3.1 million ha) in 1978. In 1979, defoliation declined (table 1 and fig. 4). Although the outbreak peaked in 1978, tree mortality lags 2 to 5 years behind severe defoliation.

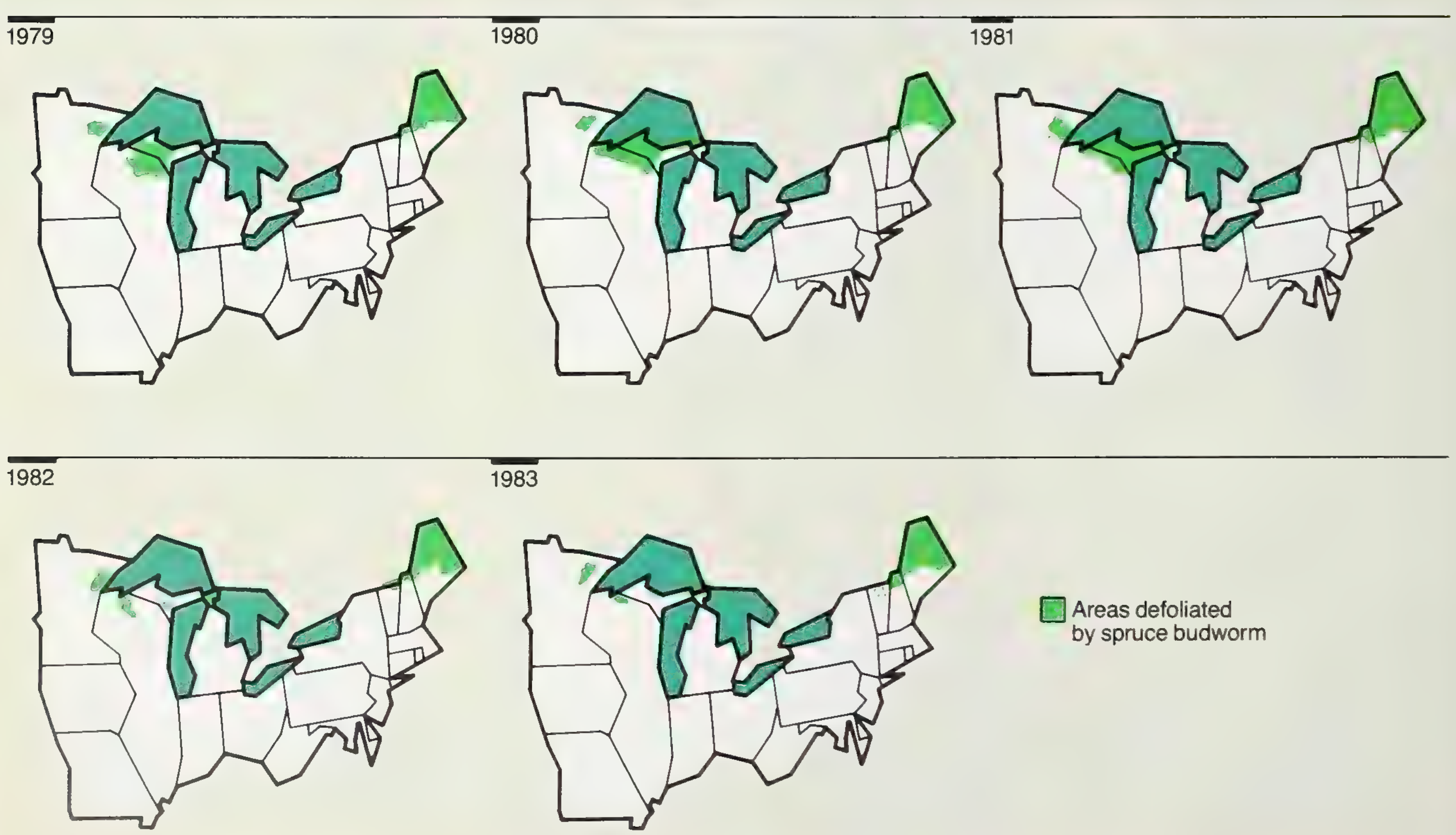
Heavy losses began in the New England States about 1981. During 1982, 50 percent—or more—of the trees in an area of approximately 240,000 acres (97,200 ha) in Maine were killed by spruce budworm. On another 300,000 acres (121,500 ha), 10 to 25 percent of the trees were dead, killed by spruce budworm. In 1983, budworm-caused mortality

***Table 1.* Number of acres of all ownerships defoliated by the spruce budworm in the Northeastern United States from 1979 to 1983**

Region/ State	1979	1980	1981	1982	1983
			Acres		
New England:					
Maine	5,900,000	5,000,000	4,000,000	3,800,000	6,000,000
New Hampshire	70,000	90,000	42,000	39,000	5,800
Vermont	101,923	110,715	96,466	153,852	178,086
Lake States:					
Michigan	258,822	859,500	161,000	129,140	145,952
Minnesota	150,000	103,000	110,000	126,700	127,000
Wisconsin	141,300	439,000	84,000	0	20,920
Total	**6,622,045**	**6,602,215**	**4,493,466**	**4,248,692**	**6,477,758**

Source: Aerial surveys conducted by the USDA Forest Service and State agencies. The USDA Forest Service data compiled by the Northeastern Area, St. Paul and Durham Field Offices.

***Figure 4.* Areas of budworm-caused defoliation in the United States from 1979 to 1983.**



resulted in Maine's losing more than 2 million cords (4.8 million m^3) of spruce and fir. Vermont, in 1982, recorded a loss of 237,235 cords (577,842 m^3). Similar losses occurred in 1983. And New Hampshire reported 25 percent mortality of spruce-fir on 8,000 to 10,000 acres (3,240 to 4,050 ha) in 1982.

In the Lake States, losses attributed to the latest outbreak began around 1980. From 1977 through 1982, approximately 485,000 cords (1.2 million m^3) were killed by the budworm (table 2). These cords represent almost one-half of the spruce-fir type. The remainder of the stands are again being defoliated after a 1- to 2-year decline.

Aerial photographs are often used to assess losses. Two kinds of film can be used. Figure 5 was taken in August 1983 over the Nicolet National Forest in Wisconsin, using normal color film. The trees killed by the spruce budworm appear gray. Figure 6 was taken over Franklin County, ME, in August 1984, using color infrared film at high altitude.

Where readily accessible, dead and dying trees were salvaged; the rest were left to rot. The total harvested, however, usually represented a small portion of the total mortality. Figure 7 compares mortality with pulpwood harvest. The sawtimber portion, not shown on the graph, came to approximately 30 percent of the pulpwood harvest so has little effect on the graph. Without suppression (table 3), mortality would undoubtedly have been even greater.

Table 2. **Total losses caused by the spruce budworm on National Forests in the Lake States from 1977 to 1982**[1]

State	National Forest	Dead trees	Average loss	Total loss
		Acres	Cords per acre[2]	Cords
Wisconsin	Chequamegon	12,080	2.11	25,489
	Nicolet	17,234	2.77	47,738
Michigan	Ottawa	54,100	3.61	195,301
	Hiawatha	37,401	2.86	106,967
Minnesota	Superior	40,707	2.70	109,909
Total		**161,522**		**485,404**

[1]These are the first spruce budworm data collected on National Forest lands in the Lake States; no data collected after 1982.
[2]To convert cords to cubic feet in the Lake States, multiply by 85.

Source: Data collected by USDA Forest Service and compiled by the Northeastern Area, St. Paul Field Office. The Minnesota Department of National Resources collected the data on the Superior National Forest.

Table 3. **Number of acres aerially treated with insecticides to control spruce budworm in the Northeastern United States from 1979 to 1983**[1]

State	1979	1980	1981	1982	1983
			Acres		
Maine[1]	2,791,000	1,213,000	1,172,692	820,051	846,382
Michigan	0	0	0	1,000[2]	0
Vermont	0	0	0	960[2]	1,712
Wisconsin	0	750[2]	2,000[3]	0	0
New Hampshire	0	750[2]	0	0	0
Total	**2,791,000**	**1,214,500**	**1,174,692**	**822,011**	**848,094**

[1]Until 1982, all reported suppression projects were conducted by the Maine Bureau of Forestry, in cooperation with USDA Forest Service.
[2]B.t. field tests sponsored by the Canada/U.S. Spruce Budworms Program (CANUSA).
[3]B.t. pilot test sponsored by the USDA Forest Service.

Source: State agencies and CANUSA EAST Program.

Prevention/Suppression

In the past, the normal course of action would have been to prevent heavy losses, regardless of the timber type or value of the trees. Over the past 5 years, however, several tactics—some new tactics and some older tactics that have been reidentified as important—have been incorporated into budworm management. This approach, known as integrated pest management, draws on several disciplines to achieve the greatest benefit at the lowest cost. These tactics are roughly divided into two categories: prevention and suppression.

Prevention. Where tree mortality is imminent, the highest value stands are harvested, leaving less valuable stands to decay. High-value stands that are 5 or more years away from harvesting are protected by thinning the stand to take out the susceptible balsam fir and leave the more resistant spruce.

In areas where stands have been clearcut, foresters may plant

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Figure 5. **Gray indicates trees that have been defoliated and killed by spruce budworm.**

trees that are less likely to host the budworm larvae; several States and private companies have established orchards to improve the planting stock. Full-scale production of superior spruce and fir seed is, unfortunately, several years away. In the interim, improved seed is being selected in the northeastern forests.

Another prevention strategy involves monitoring budworm populations with traps baited to attract male moths so that outbreaks can be detected and treated before heavy losses occur.

Suppression. After the introduction of new electronic guidance systems, such as Loran-C, precision spraying from aircraft became a reality. Today, outbreak areas are treated with both chemical and biological insecticides.

The use of biological insecticides continues to increase. The great advantage of the biologicals is that they are relatively harmless to other organisms and the environment. The bacterium *Bacillus thuringiensis* (B.t.) has given the best results. B.t. can now be applied in lower doses than before; new spray additives and research into the timing of applications have helped to improve its effectiveness. Because it affects some moths and butterflies, B.t. is also

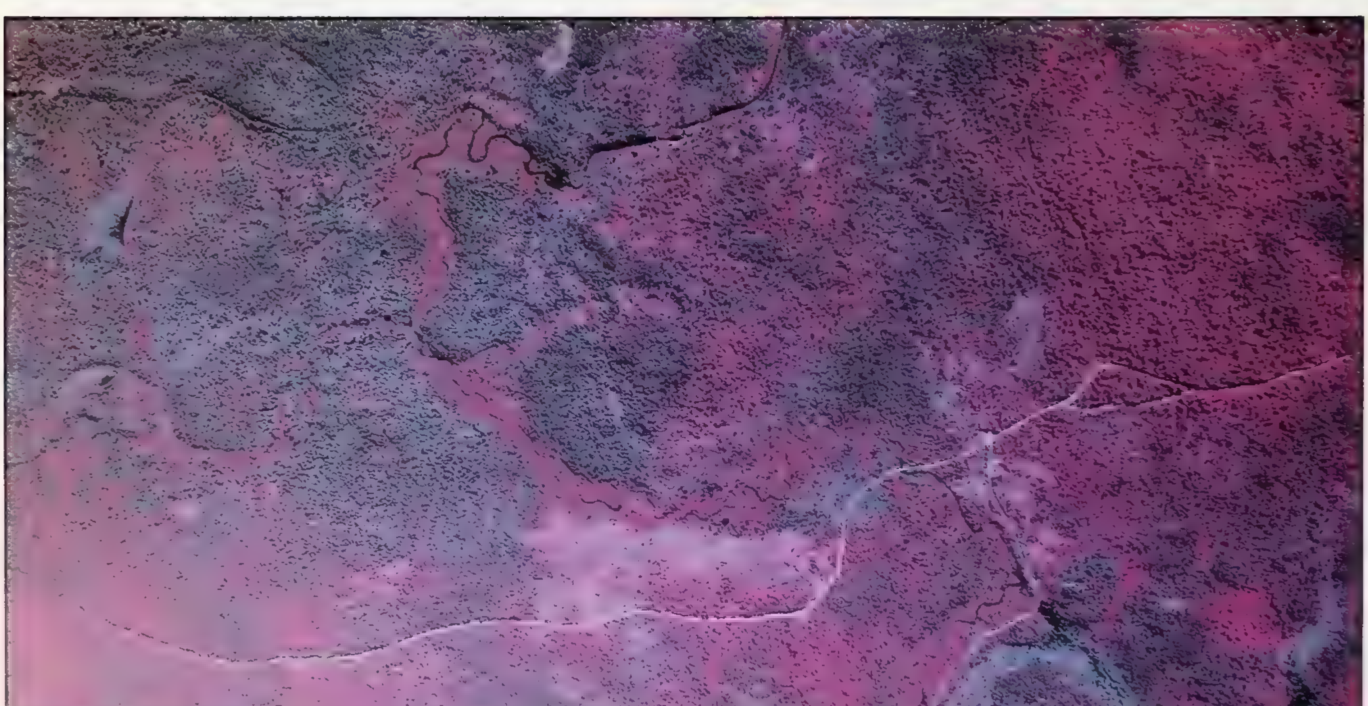

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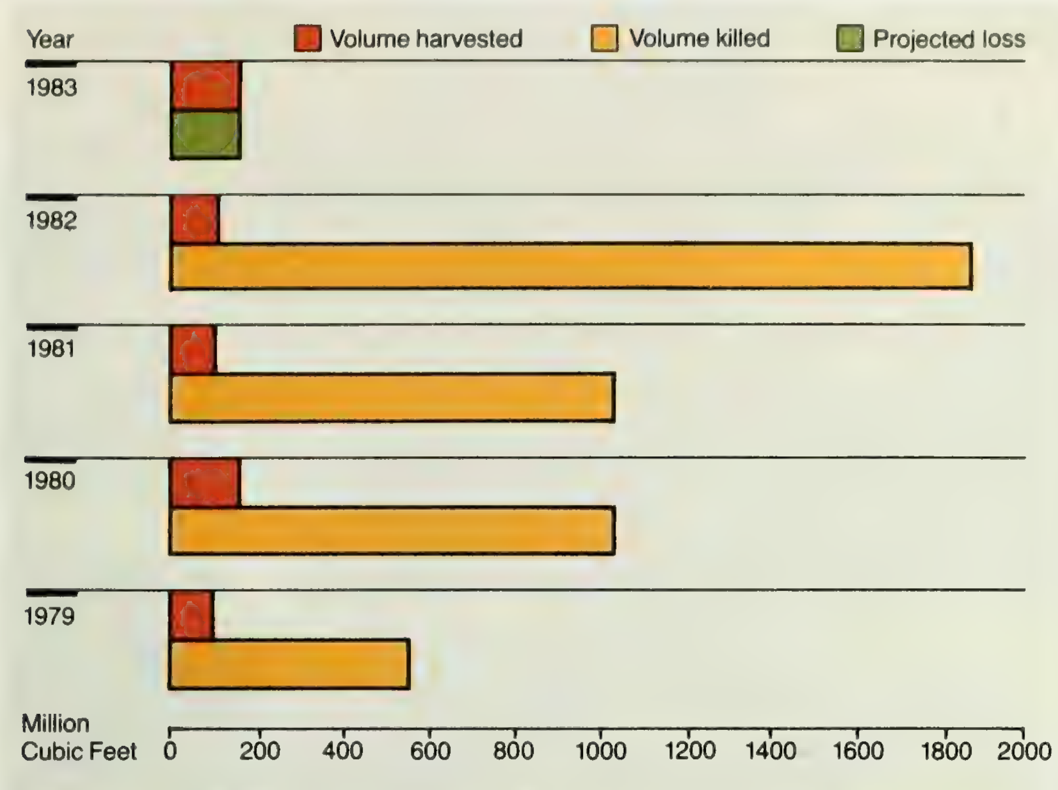
Figure 6. **Blue gray indicates trees that have been defoliated and killed by spruce budworm; maroon indicates healthy conifers; bright red is healthy hardwoods and brush; bright pink indicates grass.**

***Figure 7.* Volume of spruce and fir killed compared to pulpwood harvested in Maine from 1979 to 1983.**



Source: Data provided by Maine Bureau of Forestry

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***Figure 8.* The Fettes Method of calculating the percentage of foliage removed to determine which stands require protection.**

Photo courtesy of Maine Bureau of Forestry

***Figure 9.* Brown areas show defoliation by spruce budworm along the west branch of the Penobscot River in Maine.**

used against other insects, such as the gypsy moth. In addition to the bacterium, four viruses are known to kill only the budworm larvae. These viruses, however, are all very costly to produce and need to be applied at high dosage rates in order to be effective.

Outlook

The spruce budworm kills trees—often very quickly—thus jeopardizing long-range wood supplies (Dimond 1984) (figs. 8 and 9). The budworm can be a critical problem in States, like Maine, that rely heavily on wood and wood products: wood and wood products make up one-fourth of Maine's current exports.

In New England, defoliation is expected to continue over about 4 million acres (1.6 million ha) per year. In Maine, much of the defoliated area will remain unaffected, despite annual suppression projects on approximately 1 million acres (405,000 ha). The vast spruce-fir type in the Canadian Provinces to the east, west, and north of Maine is heavily infested. Moth flights from Canada will have a direct effect on defoliation in Maine.

Future efforts will continue to emphasize the identification of high-value stands and the protection of only those high-value stands that are known to be threatened by the budworm. Research will center on refining both chemical and biological insecticides so that they have the greatest impact on the budworm and the least impact on nontarget organisms and the environment. Landowners who have begun to plant budworm-resistant trees will expand their efforts substantially. Intensive stand management will be the key in the battle against the budworm.

Western Spruce Budworm

In 5 Years, Defoliation More Than Doubled

Written by David R. Bridgwater

A native defoliator, the western spruce budworm lives in the mixed conifer forests from southern New Mexico to Canada. Each year, this insect defoliates millions of acres. In 1983, for instance, defoliation caused by the western spruce budworm was visible on about 11 million acres (4.5 million ha).

Yet over most of its range, the western spruce budworm does its damage unobtrusively. The budworm larvae (fig. 1) feed on the expanding buds and new needles of host trees. Although this feeding saps the tree, the damage is hardly visible during the first or even the second year of successive defoliation. But when the budworm repeatedly defoliates a tree, the tree begins to die from the top downward (fig. 2). Defoliation also causes the tree to grow more slowly.

The budworm usually develops from egg to adult in 1 year. In August, moths emerge from pupal cases, and females lay eggs on the needles of host trees. When the eggs hatch, the tiny larvae spin silken webs in sheltered locations on the tree, where they spend the winter. The following May, the larvae come out from their hiding places, bore into developing buds, and begin feeding. As the new shoots unfurl, the larvae spin loose webs between the needles and continue to feed. When fully grown, the larvae pupate. Adult moths emerge from pupal cases in August. The life cycle begins again.

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***Figure 1.* Full-grown larva of western spruce budworm.**

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***Figure 2.* Repeated defoliation by western spruce budworm is killing these trees near Ward, CO.**

The larvae feed on a variety of trees. The most common hosts are Douglas-fir; true firs, such as grand fir; and spruce. The larvae also feed on coniferous trees that are planted as ornamentals, such as Norway spruce and Scotch pine.

Historical Perspective

Damage from pests is a normal part of forest activity. One tree may host several different species of insects; when man's influence was slight, the budworm, like all other insects, played a part in the renewal of the western forests.

Photo courtesy of Bruce Montgomery, University of Michigan

Figure 3. Douglas-fir cones damaged by the western spruce budworm or coneworms.

F-702990

Figure 4. Mature Douglas-fir, defoliated by western spruce budworm, produced adventitious foliage throughout the length of its crown.

The budworm killed older trees, and fire, following an outbreak, made room for young trees to develop.

Around 1920, people in the Western States began to harvest more intensively. At the same time, effective prevention of forests fires became possible. Thus, the makeup of the western coniferous forests began to change. Ponderosa pine, a nonhost species, was harvested, leaving Douglas-fir and true firs, host species. Once fire might have removed these trees. But by preventing fires, we helped create forests of susceptible host trees.

The western spruce budworm was first reported in 1914 in Oregon, but budworm was not recognized as a serious threat to western forests until 1922, when two outbreaks were reported near Priest Lake in northern Idaho. Since then, many outbreaks have occurred in the West.

The outbreaks follow no apparent pattern or trend. Most of the early outbreaks lasted for a few years and then subsided naturally. Others persisted longer. An outbreak in the northern Rocky Mountains that began in 1949 persisted for more than 30 years.

Many areas where damage is heavy are former ponderosa pine stands that have changed to white or grand fir as a result of fire exclusion policy and past cutting practices that leave true fir and harvest the more valuable pines.

Resources Affected

Timber Regeneration. Budworm feed not only on the needles but also on the flowers and on the cones of host trees. The budworm larvae prefer to feed on the developing cones. But if they damage the conelets so that the new cones shrivel and dry out, the larvae will feed on older cones.

In some Douglas-fir stands, nearly all cones may be damaged or destroyed by feeding larvae, especially when larvae are plentiful and cone crops are sparse (fig. 3).

The damage to the cones reduces the amount of available seed. In addition, if several years of heavy defoliation have killed the top of a host tree, the tree will be unable to grow new cones for many years, even after budworm populations have subsided.

The budworm influences regeneration in another way. Young trees, trees less than 5 feet (1.5 m) tall and 1 to 2 inches (2.5 to 5.0 cm) in diameter, are especially vulnerable when grow-

Figure 5. **Areas of visible defoliation from 1979 to 1983.**

ing beneath mature trees. Larvae disperse from the overstory and feed on the small trees below. Small trees have relatively few needles and shoots and can be seriously deformed or killed by only a few larvae.

The mortality of these new trees, coupled with the damage to the cones, can significantly delay natural regeneration, particularly when partial cutting methods leave host trees in the residual overstory. Some small trees survive, however, probably because many larvae dispersing to the forest floor are eaten by insects and small mammal predators.

Timber Yield. After 3 or more years of sustained feeding, young stands of Douglas-fir, true firs, and spruce can be almost entirely defoliated, reducing growth both in diameter and height. The tops of some trees are killed, which often results in stem deformity, multiple leaders, or death of the entire tree. In young western larch stands, several years of defoliation deforms the trees' crowns and reduces their height growth by as much as 30 percent.

In mature stands, budworm defoliation also reduces growth. Repeated defoliation sometimes kills the tree's crown or the tree itself. Recent studies in Idaho and Washington showed that radial growth of defoliated trees declined about 25 percent over a 5-year period, whereas radial growth of undefoliated, nonhost trees in the same stand declined only 2 percent. Larger, dominant trees can be so severely defoliated that the tops die, but the trees remain alive because they produce adventitious buds, that is, buds growing in abnormal positions on the branches or main stem (fig. 4).

In both young and mature stands, trees severely defoliated by the western spruce budworm may be predisposed to one or

Table 1. **Acres of western spruce budworm defoliation on all landownerships in the West from 1979 to 1983**

State	1979	1980	1981	1982	1983
			Acres		
Arizona	87,143	66,458	120,200	31,450	19,925
Colorado	930,000	1,052,000	1,400,000	1,800,000	2,600,000
Idaho	1,124,045	1,244,170	1,402,175	2,262,635	2,399,378
Montana	2,185,052	848,342	894,713	2,210,200	2,545,326
New Mexico	44,496	232,702	358,325	337,035	330,900
Oregon	28,590	2,340	312,640	1,530,730	2,439,168
Utah	0	6,000	5,100	51,400	78,500
Washington	378,070	126,790	30,050	9,270	37,850
Wyoming	235,025	399,560	971,240	445,276	586,221
Total	**5,012,421**	**3,978,362**	**5,494,443**	**8,677,996**	**11,037,268**

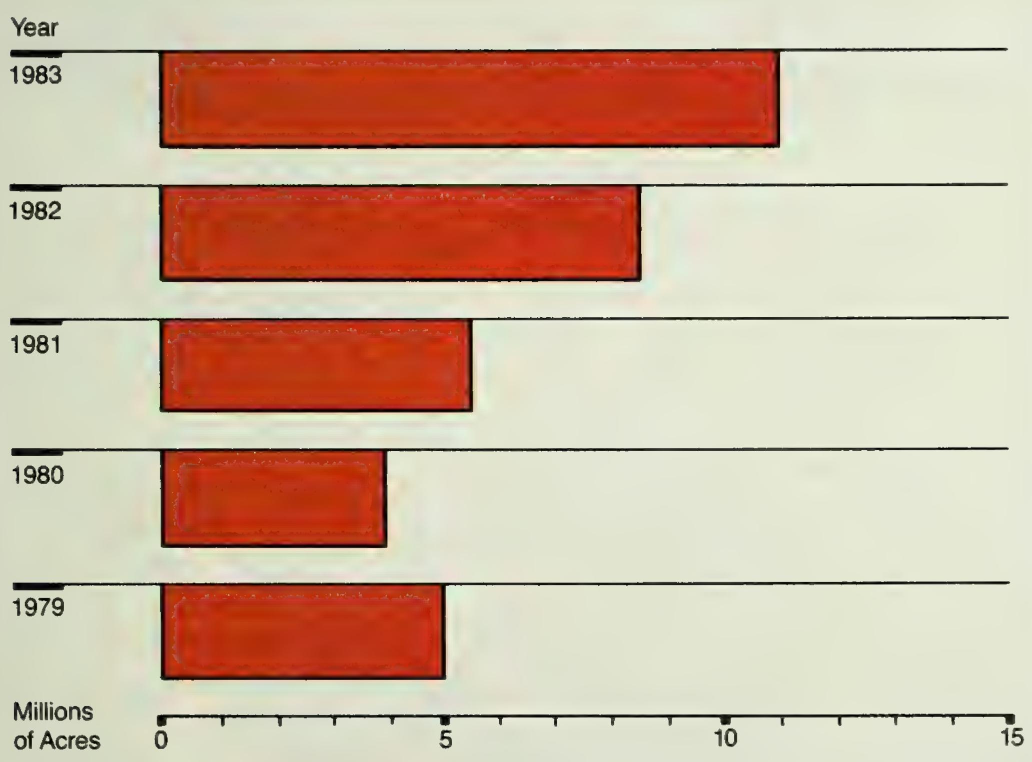
Source: Data compiled from aerial surveys conducted in the summer by the USDA Forest Service and State agencies.

Table 2. **Western spruce budworm control projects from 1979 to 1983[1]**

Year	State	Acres treated	Control agent
1979	Idaho	139,000	Acephate, carbaryl
	Oregon	34,440	Carbaryl
1982	New Mexico	68,300	Carbaryl, *Bacillus thuringiensis*
	Oregon	178,549	Acephate, carbaryl
1983	New Mexico	37,600	Carbaryl, *Bacillus thuringiensis*
	Oregon	524,561	Carbaryl, *Bacillus thuringiensis*, mexacarbate

[1]Acres of aerially visible defoliation do not reflect areas needing treatment.

Figure 6. **Acres of defoliation by western spruce budworm from 1979 to 1983.**



more tree-killing bark beetles, primarily the Douglas-fir beetle and the fir engraver beetles.

Because the budworm rarely kills trees over large areas, as the Douglas-fir beetle or the mountain pine beetle does, its direct effect on other resources is speculative.

Trend from 1979 to 1983

Defoliation increased from 5 million acres (2 million ha) in 1979 to 11 million acres (4.5 million ha) in 1983 (table 1, figs. 5 and 6). Growth loss appears to be the major effect, although some top-kill and mortality of scattered trees are also occurring.

Prevention/Suppression

Table 2 lists treated acreages. The control project in Oregon in 1983 was the largest all-helicopter project ever undertaken against the western spruce budworm. In addition, in 1982, the bacterium *Bacillus thuringiensis* was first used operationally against the western spruce budworm.

A promising area is the use of silvicultural treatments to reduce the vulnerability of forests to future western spruce budworm outbreaks. Trees can be cut to control stand density, improve vigor and growth, and favor nonhost species.

Outlook

Foresters generally regard the western spruce budworm as the most persistent and destructive foliage-feeding insect in the West. Although not a spectacular tree-killing insect, the western spruce budworm harms forests by reducing growth and productivity.

Since the 1920's, forest conditions have been created that favor western spruce budworm outbreaks. We will probably need another 60 years or so to reduce the hazard.

Candidates for Control Through Cultural Management

Written by David W. Johnson and Frank G. Hawksworth

Millions of years ago, the dwarf mistletoes and western conifers began evolving together. Today, the dwarf mistletoes are one of the most widespread and damaging groups of forest diseases in North America (Hawksworth 1979). They range from Alaska and northern Alberta south to Mexico, Guatemala, and Honduras. The losses they cause are not as spectacular as those caused by fire or insects; however, their effects are just as devastating. Each year, these plants account for about 8 percent of the pest-caused losses in the United States.

The dwarf mistletoes are parasites belonging to the genus *Arceuthobium*. Sixteen species of dwarf mistletoes occur in the United States (Hawksworth and Wiens 1972). These plants depend upon their hosts for organic and inorganic nutrients and water, which they obtain from a rootlike absorbing system that becomes embedded in the bark and wood.

On the stems and branches of conifers, the dwarf mistletoes grow leafless, jointed shoots (fig. 1). The shoots bear male or female flowers.

The female flowers bear the fruits and seeds that spread the disease. Each fruit, equipped with an explosive mechanism, holds a single seed. At maturity, the fruit contracts violently and shoots the seed through the air at a speed of 60 miles (96 km) per hour and as far as 50 feet (15 m), although the average distance is 10 to 20 feet (3 to 6 m).

A sticky substance called viscin surrounds each seed and holds it fast to any surface it strikes. The viscin coating also provides a moist medium for germination.

Some seeds land on needles (fig. 2). During rainy periods, the viscin becomes a lubricant, causing the seed to slide down the needle. Seeds may lodge at the base of the needle, germinate (fig. 3), and start new plants. Plants take 4 to 6 years to mature.

The dwarf mistletoes grow only on conifers and are generally host specific; that is, they are usually confined to a single host species or group of closely related species.

Historical Perspective

The dwarf mistletoes and western conifers began evolving together in North American forests about 25 million years ago. Large fires also played a role in

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Figure 1. **Lodgepole pine dwarf mistletoe plants on lodgepole pine in Colorado.**

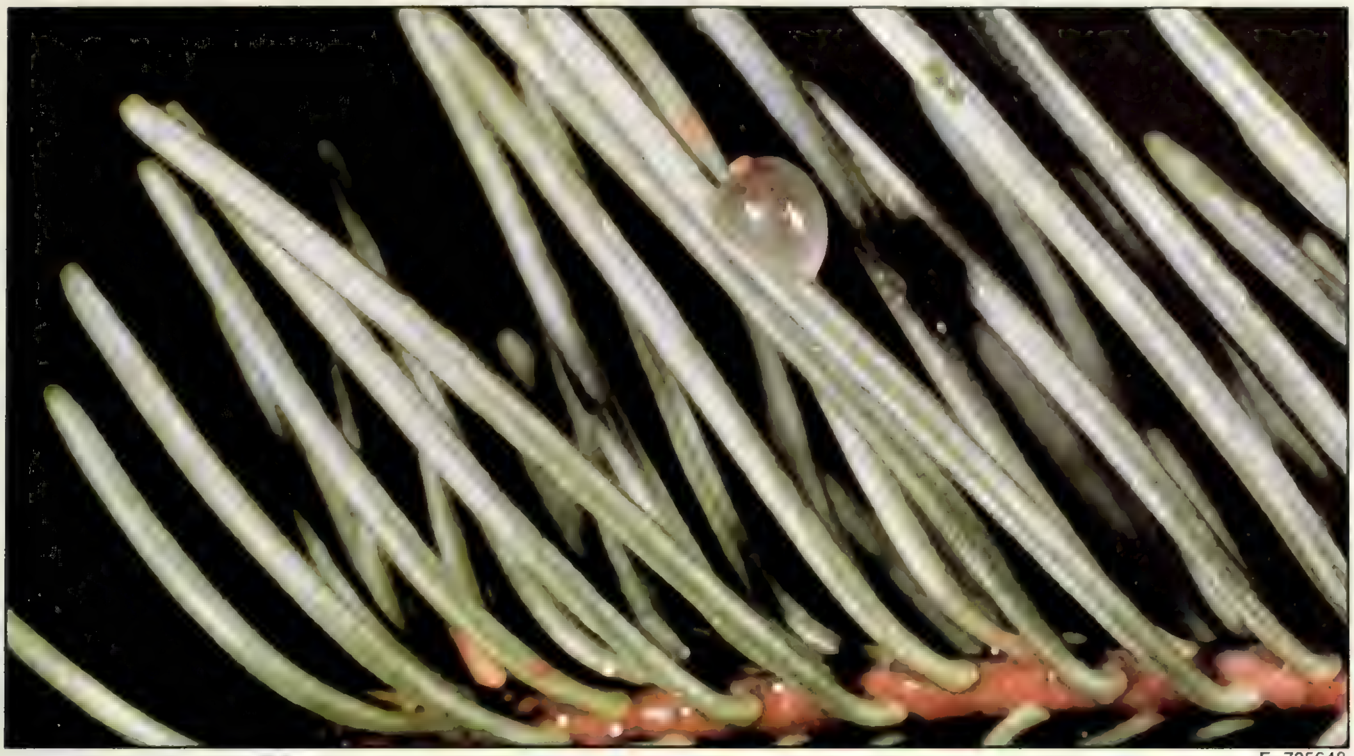

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Figure 2. **Surrounded by viscin, a mistletoe seed is lodged on a needle.**

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Figure 3. **At the base of a needle, an embedded mistletoe seed begins germinating.**

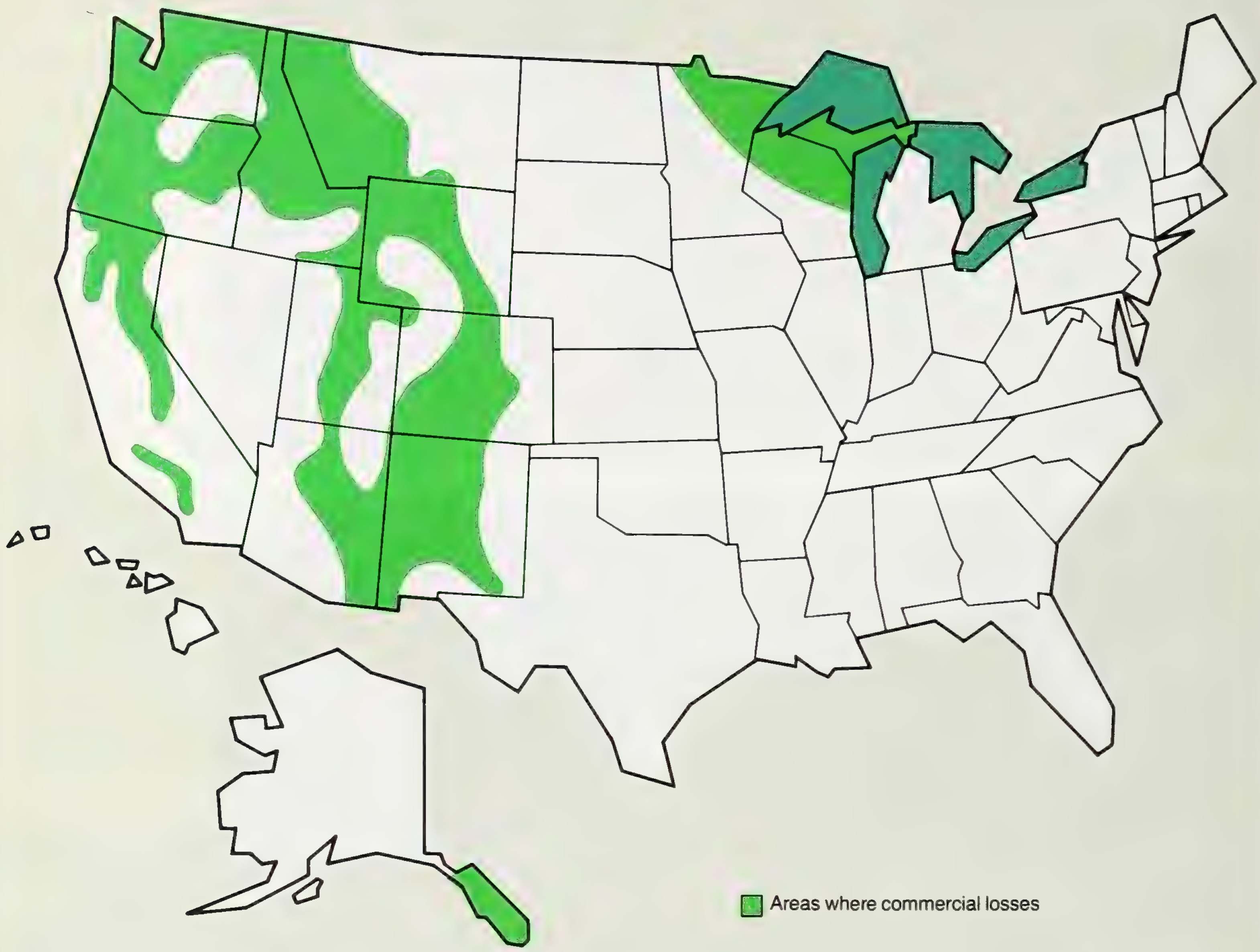
shaping these forests. Fires changed forest composition and sanitized infested stands by killing the parasite when they killed the host tree. The new, replacement forests were largely free of mistletoes.

Silvicultural practices to control dwarf mistletoes have been advocated since the early part of the century; however, these efforts were limited to removing only the most infected overstory trees during the course of logging operations. This type of partial cutting actually increased the amount of infection in residual stands. Leaving infected trees of no commercial value in regeneration areas also increased the problem.

Forest roads and timber markets began improving in the 1950's. Improved access and markets, coupled with more specific guidelines from research, made it possible for managers to take more effective action against the dwarf mistletoes.

In the past 10 years, dwarf mistletoe control programs have been more consistent. Most recently (1979–83), an average of $860,000 a year was spent on dwarf mistletoe control. The money was used for pretreatment surveys on 900,000 acres (364,000 ha) and to treat 74,000 acres (30,000 ha). Thousands of additional acres are treated each year through normal stand improvement and timber harvesting operations. The Federal Jobs Bill program, started in 1983, also helped accomplish timber stand improvement projects that otherwise would not have been undertaken.

Figure 4. **Geographic distribution of dwarf mistletoes causing losses in commercially important tree species.**



Resources Affected

Timber. In Western North America, practically all members of the pine family—including the pines, true firs, spruces, Douglas-fir, larch, and hemlock—are parasitized. Commercially important principal hosts are listed in table 1; the areas where these significant hosts are infested with dwarf mistletoes are shown in figure 4. The vast southern pine forests of the United States are not affected; cedars, cypress, junipers, redwood, and giant sequoia are immune.

The most important effect of dwarf mistletoes is volume reduction: when trees are heavily infected, dwarf mistletoes reduce both height and diameter growth and increase mortality.

The first symptom of infection is a swelling of host tissues. Later, the swellings enlarge and produce dense masses of distorted branches called witches' brooms (fig. 5). As the parasite spreads through the crown, the tree's growth is gradually reduced. Eventually, the top weakens and dies, diameter growth ceases, and the tree dies. Insects, particularly bark beetles, may cause an earlier death by attacking weakened trees. Other pests, such as decay fungi, enter wounds and swellings created by the mistletoes.

The rate at which the tree dies largely depends upon its age when first infected and the amount of infection. Young trees with stem infections tend to die quickly. Older trees with well-developed, vigorous crowns may

not show measurable effects from the parasite for years after initial infection.

Besides retarding growth and causing death, dwarf mistletoe infection results in pitch-soaked cankers and large knots, which reduce the quality of the wood. In some cases, trees may become so deformed that they have no commercial use whatsoever.

Furthermore, heavily infected trees produce fewer cones and less vigorous seed than healthy trees, so they should not be left as seed trees. And heavily infested stands full of dead and dying trees provide a source of fuel for crown fires.

Recreation. Dwarf mistletoes adversely affect recreation values by killing trees in recreation sites. Not only are larger trees killed but larger, infected, overstory trees can infect and kill all the understory trees of the same species. The long-term consequence of untreated dwarf mistletoe infection is an even-aged, infested, declining overstory that will eventually be replaced by nonsusceptible trees or shrubs.

In addition, the decay and canker fungi associated with dwarf mistletoe infection kill or weaken branches so that they are susceptible to wind breakage, thus increasing the hazard to recreationists.

Other Resources. Although the debilitating effects of the mistletoes on tree growth and forest productivity are well documented, their effects on other resources have not been fully assessed. The effects on wildlife, for example, may be positive or negative, depending upon the particular ecological needs of the species. Dead trees provide nesting sites for snag-dependent bird species. Witches' brooms also provide cover and nesting sites for many birds and mammals. Large areas infested with mistletoes have a more open forest canopy, favoring certain bird and animal species. As these openings

Table 1. **Commercially important tree species in the United States that are principal hosts of dwarf mistletoes**

Important principal hosts	Distribution	Dwarf mistletoe (common name)	Dwarf mistletoe (scientific name)
Douglas-fir	Arizona, California, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, Wyoming	Douglas-fir dwarf mistletoe	*Arceuthobium douglasii* Engelm.
Black spruce	Michigan, Minnesota, Wisconsin	Eastern dwarf mistletoe	*A. pusillum* Peck
Western hemlock	Alaska, Oregon, Washington	Hemlock dwarf mistletoe	*A. tsugense* (Rosendahl) G. N. Jones
Western larch	Idaho, Montana, Oregon, Washington	Larch dwarf mistletoe	*A. laricis* (Piper) St. John
Lodgepole pine	California, Colorado, Idaho, Montana, Oregon, Utah, Washington, Wyoming	Lodgepole pine dwarf mistletoe	*A. americanum* Nutt. ex Engelm.
Red fir	California, Oregon	Red fir dwarf mistletoe	*A. abietinum* f. sp. *magnificae* Hawksw. & Wiens
Ponderosa pine	Arizona, Colorado, New Mexico, Utah	Southwestern dwarf mistletoe	*A. vaginatum* subsp. *cryptopodum* (Engelm.) Hawksw. & Wiens
Ponderosa pine	California, Idaho, Oregon, Washington	Western dwarf mistletoe	*A. campylopodum* Engelm.
Sugar pine	California, Oregon	Sugar pine dwarf mistletoe	*A. californicum* Hawksw. & Wiens
White fir	California, Oregon, Utah	White fir dwarf mistletoe	*A. abietinum* f. sp. *concoloris* Hawksw. & Wiens


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Figure 5. **Witches' brooms on infected lodgepole pine in Colorado.**

regenerate to either the same tree species or other tree species and brush, greater vegetation diversity will result. Profound changes in both stand structure and species composition can occur. The mistletoe plants themselves provide a food source for some rodents, birds, and insects.

Status From 1979 to 1983

Although environmental factors, such as drought and air pollution, can dramatically increase mortality of infected trees, the status of the dwarf mistletoes does not change markedly from year to year. Mistletoes spread slowly, at a rate that averages 1 to 2 feet (0.3 to 0.6 m) per year. The rate of spread is balanced by timber management activities and direct suppression, which reduce the acreage slightly each year; therefore, the total area infested and annual loss usually remain relatively constant.

The acreage and loss figures in table 2 represent any year from 1979 to 1983. Volume losses reported are only for commercial forest lands and include both growth loss and mortality.

These figures are conservative. Not all forest land and types of ownerships are included: the figures for Arizona, New Mexico, Colorado, and eastern Wyoming include only National Forest lands. Nevertheless, the growth loss and mortality attributed to dwarf mistletoes total more than 393 million cubic feet (11 million m^3) each year. The total growth loss and unsalvaged mortality from all insects and diseases averages 5 billion cubic feet (140 million m^3); dwarf mistletoes, therefore, cause about 8 percent of the growth loss and mortality.

Table 2. **Annual mortality and growth loss caused by dwarf mistletoes in commercial forests from 1979 to 1983**[1]

State	Area infested	Annual loss
	1,000 acres	1,000 cubic feet
Montana	2,416	33,250
Northern Idaho	713	13,420
Colorado[2]	638	5,490
Eastern Wyoming[2]	361	4,960
Arizona[2]	982	8,140
New Mexico[2]	1,793	16,570
Southern Idaho	2,511	28,860
Utah	461	4,750
Nevada	62	580
Western Wyoming	276	3,290
California	2,200	120,000
Oregon	4,885	76,560
Washington	3,575	55,440
Michigan	74	3,740
Minnesota	155	6,740
Wisconsin	54	670
Alaska	1,500	11,000
Total	**22,656**	**393,460**

[1]These losses were compiled from USDA Forest Service estimates and reports; the States are grouped by USDA Forest Service region.
[2]National Forest lands only.

Cultural Management

The dwarf mistletoes are most easily and economically treated by silvicultural practices. Several features of these parasites make them ideal candidates for cultural management (Hawksworth 1979).

- Dwarf mistletoes require a living host to survive. Once an infected tree or branch is cut, the mistletoe dies. There is no need to destroy the slash.

- Mistletoes are generally host specific; that is, they are usually confined to a single host species or group of closely related species. Immune or lightly infected species can be favored during stand treatments.

- Dwarf mistletoes spread slowly. Seed dispersal from a tall, isolated tree is usually limited to less than 60 feet (18 m). In even-aged stands, spread is even more limited, averaging 1 to 2 feet (0.3 to 0.6 m) per year.

- Dwarf mistletoes have a long life cycle: mature plants take 4 to 6 years to develop from seeds. From a practical standpoint, this long life cycle means that the amount of infection builds slowly. After a stand is treated, it remains relatively free of mistletoe.

- The signs and symptoms of dwarf mistletoe infection—the plant shoots, the swellings, and witches' brooms—are readily visible, and detailed surveys of infested stands are an essential ingredient to successful control programs.

Prevention/Suppression

Successful strategies have been developed specifically for dwarf mistletoe control. These strategies

are aimed at either prevention or suppression.

Prevention. It is much more efficient to prevent mistletoes from becoming established than to remove them from infested stands or to replace severely infested stands. Prevention, therefore, should be the priority in a mistletoe control program.

- Designing treatment units to take advantage of natural or manmade barriers, such as roads, streams, or meadows, that prevent reinvasion from adjacent infested stands.

- Removing **all** infected trees before an area is planted or naturally regenerated (fig. 6).

- Using clearcuts (minimum of 20 acres (8 ha)) to advantage when harvesting infested stands. Stands should not be cut in long, narrow strips.

- Regenerating stands with disease-free seed trees or shelterwood. If infected trees must be left, they should be removed before the seedlings are 3 feet (1 m) tall or 10 years old.

- Favoring nonsusceptible tree species when regenerating a stand or partial cutting.

These strategies reduce the likelihood of dwarf mistletoe spreading into a healthy stand.

Suppression. If a stand is already infested, the infected overstory and then the infected understory trees can be removed. Foresters call this strategy sanitation thinning and use it only in lightly infested stands. Prescribed burning is another useful suppression strategy (fig. 7). Burning not only kills infected trees but also encourages regeneration. Other suppression strategies include selecting crop trees to retain as many noninfected trees as possible, replacing severely infested stands with healthy stands, and sanitation thinning in lightly infested, pole-sized stands.

Which treatment or combination of treatments (fig. 8) is used should depend upon conditions in a stand. Foresters now have a valuable tool to help them assess these conditions: computer models. A variety of management practices can be entered into a model. The model then predicts the yields of an infested stand (Edminster 1978). Using the models, foresters can compare outputs and analyze control costs, thereby deciding on the best treatment for each infested stand.

Individual Trees. When valuable individual trees are lightly infected, these high-value trees can be pruned (Lightle and Hawksworth 1973). This technique is not recommended if more than half the tree crown is infected. All living branches up to two or more whorls of branches above the highest visibly infected branch should be pruned. Trees should be examined about 5 years after they have been pruned and treated again, if necessary.

Outlook

Although no effective chemical or biological controls have been developed, these techniques

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***Figure 6.* Roller chopping a lodgepole pine clearcut to prepare the site and to destroy infected residual trees.**

F-705652

Figure 7. **Lodgepole pine stand severely infested with lodgepole pine dwarf mistletoe is being replaced by means of prescribed fire; Colorado.**

would probably not replace proper silvicultural management of forest stands.

Research continues into techniques for quantifying the effects of dwarf mistletoes, including rates of spread and intensification in managed stands. Growth and yield models need to be developed for other forest ecosystems. Extension and training programs could be improved.

In addition, dwarf mistletoe control should continue to be integrated into forest plans and harvesting operations. Where the disease is present, for example, timber cutting contracts should contain clauses pertaining to the felling of infected, nonmerchantable trees. And the present demands for fuelwood mean that we can now harvest many small-diameter, highly defective stands that were previously left untreated. As these stands are harvested, they will be replaced by disease-free stands.

The mistletoes are widespread, but in intensively managed stands, foresters are making good progress toward reducing their effects. Still, the dwarf mistletoes will continue to cause tremendous losses each year for many years to come.

F-705653

Figure 8. **Combination of cultural treatments in Colorado: severely infested lodgepole pine in the foreground has been clearcut; the stand in the background has been sanitation thinned.**

Fusiform Rust

Site-Specific Options Promise To Slow Epidemic

Written by Robert L. Anderson

This disease flourishes across the Southeast, killing or deforming millions of slash and loblolly pines each year. Annual losses may exceed $110 million (Powers and others 1975).

Fusiform rust is caused by a fungus native to North America. The fungus infects loblolly and slash pines, the most susceptible southern pine species. Longleaf pine and pond pine are sometimes infected, but not to the same degree as loblolly or slash pines. In contrast, spruce, sand, Virginia, and shortleaf pines are highly resistant to infection.

Infections on pines start as slight swellings, which enlarge to form spindle-shaped swellings on the branches or main stem (fig. 1). The swellings on larger main stems may become cankers, areas of diseased tissue that encircle the stem.

In the spring, orange-yellow blisters form on the swellings (fig. 2). These blisters release aeciospores, the spore stage of the fungus that infects the leaves of the alternate host, oak. About 10 days later, orange-colored uredia develop on the underside of the oak leaf (fig. 3). Later, brown, hairlike telia form on the leaf. The telia produce basidiospores, the spore stage that reinfects pine. Oak, the alternate host, is not severely damaged.

Historical Perspective

Before 1930, fusiform rust was a botanical curiosity rather than an agent causing economic losses. At that time, slash and loblolly pines grew naturally, and wildfires kept the alternate host, oak, at relatively low levels.

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Figure 1. **Spindle-shaped fusiform rust swelling on branch.**

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Figure 2. **Orange-yellow blisters on pines release aeciospores.**

Figure 3. Uredia on the underside of an oak leaf.

Since 1930, however, more than 20 million acres (8.1 million ha) have been planted with even-aged stands of primarily slash and loblolly—pines that are the most susceptible to fusiform rust infection. Both species were moved outside their natural ranges. At the same time, the number of oaks increased as fire control programs were established.

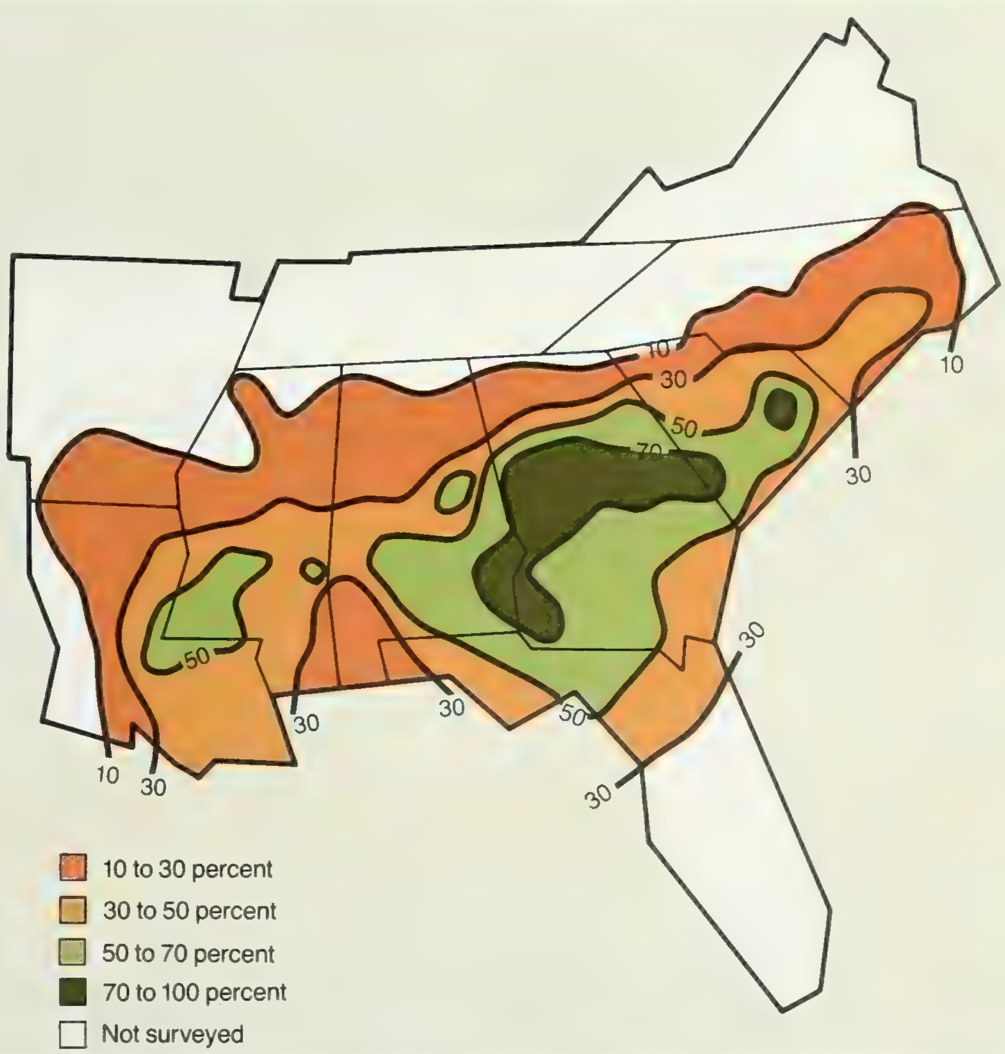
Under these conditions, fusiform rust has flourished across the Southeast. Despite occasional years of low infection, the annual rates of infection have escalated. Both the intensity of infection and the acres affected have increased about 2 to 3 percent per year over much of the southern pine type. New plantations of susceptible slash or loblolly pine may become 100 percent infected (Dinus and Schmidt 1977).

Resources Affected

Tree mortality caused by fusiform rust may increase runoff; create or increase wildlife habitat; pose a safety hazard in recreation areas; and increase forage. But these relationships have not been documented.

What have been documented are the effects of fusiform rust on the timber resource: losses occur primarily as mortality in young stands and quality loss in older stands. Also, the disease is more severe in plantations than in naturally regenerated stands, and

Figure 4. Zones of fusiform rust by infection level for loblolly pine.



mortality is greatest when trees are infected soon after they are planted. Stands with moderate to high mortality must either be replaced or grown to harvest with greatly reduced stocking. Infected trees that remain alive are frequently predisposed to wind breakage. Wood with galls or cankers makes products of lower value. Other effects, often unrecognized, include those associated with early or more frequent thinning.

Pest Status

Fusiform rust is found in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Texas, and Virginia. About 14 million acres (5.7 million ha) have at least 10 percent of the slash and loblolly pines infected on or within 12 inches (30.5 cm) of the main stem (table 1). Georgia has about 29 percent of the total acreage with 10-percent infection; Virginia has less than 1 percent. Tables 2 and 3 show the acres having at least 30 percent and at least 50 percent of the trees with main stem infection or potential main

Table 1. **Slash and loblolly pine stands in the South that have about 10 percent or more of the trees infected with fusiform rust on or within 12 inches of the main stem—1983**

	Landownership class				
State	National Forest	Other Federal	State	Private	Total by State
			Acres		
Alabama	61,900	20,100	20,100	1,938,900	2,041,000
Arkansas	6,500	1,200	800	50,400	58,900
Florida	47,000	28,400	22,500	1,020,200	1,118,100
Georgia	78,500	71,600	14,800	3,871,700	4,036,600
Louisiana	61,300	15,700	31,400	1,461,700	1,570,100
Mississippi	86,500	6,700	6,800	1,585,200	1,685,200
North Carolina	28,700	9,600	9,700	1,296,300	1,344,300
South Carolina	73,081	45,819	14,699	1,362,877	1,496,476
Texas	36,500	1,300	1,400	461,800	501,000
Virginia	0	0	0	6,000	6,000
Total	**479,981**	**200,419**	**122,199**	**13,055,077**	**13,857,676**

Table 2. **Slash and loblolly pine stands that have 30 percent or more of the trees infected with fusiform rust on or within 12 inches of the main stem—1983**

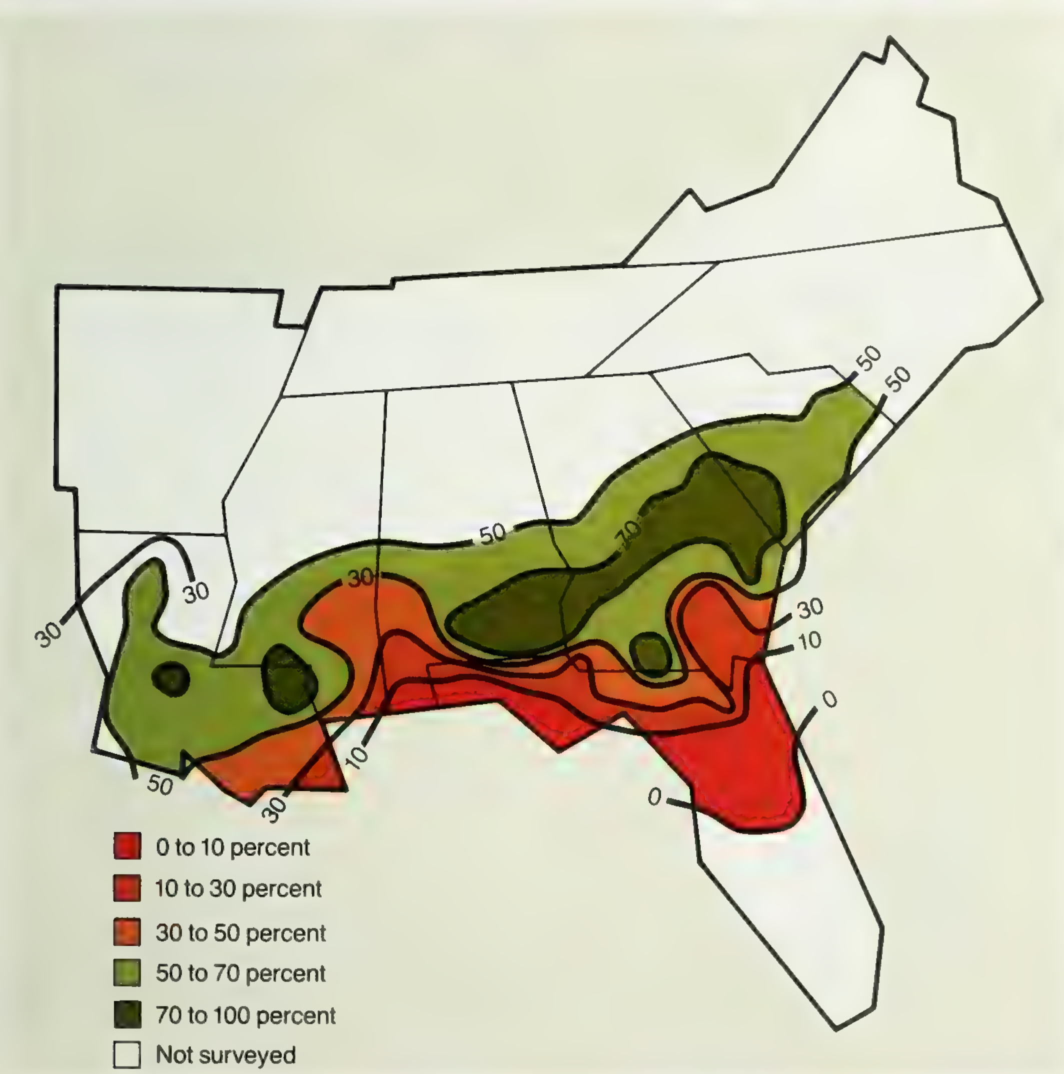
	Landownership class				
State	National Forest	Other Federal	State	Private	Total by State
			Acres		
Alabama	26,631	8,138	8,138	773,156	816,063
Arkansas	2,282	427	213	17,951	20,873
Florida	31,552	19,063	15,129	640,446	706,190
Georgia	32,309	36,564	5,625	2,039,947	2,114,445
Louisiana	20,954	5,456	10,913	507,470	544,793
Mississippi	38,991	2,758	2,852	648,262	692,863
North Carolina	8,074	2,782	2,860	370,650	384,366
South Carolina	33,258	14,114	20,829	569,709	637,910
Texas	10,850	438	65	204,462	215,815
Virginia	0	0	0	4,300	4,300
Total	**204,901**	**89,740**	**66,624**	**5,776,353**	**6,137,618**

Table 3. **Slash and loblolly pine stands that have about 50 percent or more of the trees infected with fusiform rust on or within 12 inches of the main stem—1983**

State	Landownership class: National Forest	Other Federal	State	Private	Total by State
	Acres				
Alabama	11,180	3,366	3,366	319,800	337,712
Arkansas	1,018	156	78	6,578	7,830
Florida	12,077	7,296	5,791	244,631	269,795
Georgia	12,776	7,834	2,419	877,196	900,225
Louisiana	8,022	2,112	4,225	196,450	210,809
Mississippi	16,370	1,133	1,175	266,373	285,051
North Carolina	2,959	1,030	1,069	138,946	144,004
South Carolina	13,479	5,901	8,710	237,941	266,031
Texas	3,965	161	24	74,973	79,123
Virginia	0	0	0	2,416	2,416
Total	**81,846**	**28,989**	**26,857**	**2,365,304**	**2,502,996**

stem infection. At all levels of infection, private landowners have the majority of the affected acreage; State-owned lands are least affected. (The estimates in tables 1, 2, and 3 were derived primarily from Forest Inventory and Analysis data.)

Figure 5. **Zones of fusiform rust by infection level for slash pine.**

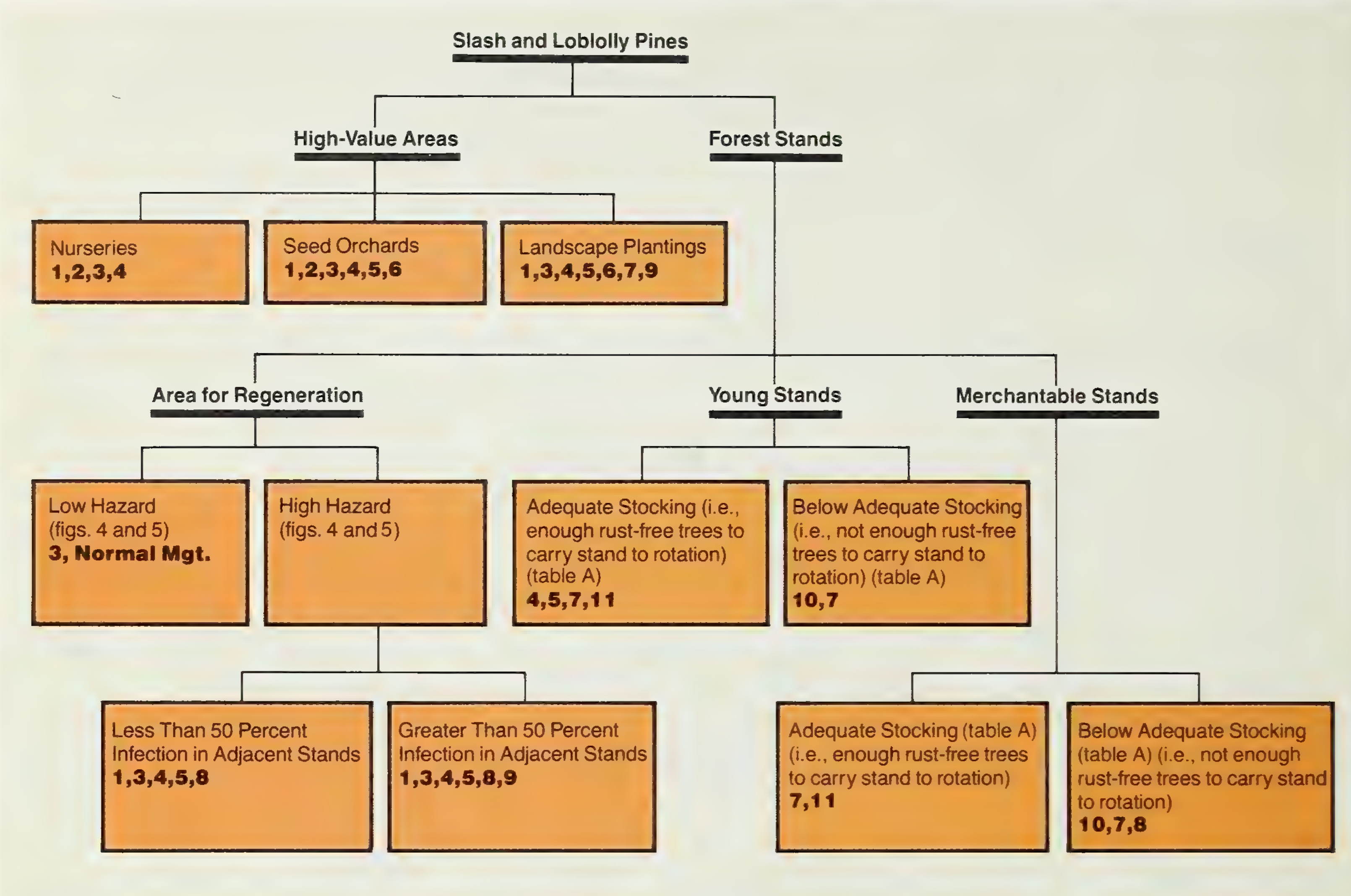


The corresponding maps (figs. 4 and 5) depict the levels of fusiform rust infection for loblolly and slash pines (Anderson and Mistretta 1982, Phelps and Czabator 1978). These geographic estimates should be modified on site: specific areas within a zone may be different from the average for the area. Most managers define high-hazard areas as areas with 50 percent or more of the trees infected, but this decision will vary according to the land manager and the resource objective.

Powers and others (1975) reported that about 109,894,000 cubic feet (3,112,200 m³) are lost each year throughout the Southeast to fusiform rust. This volume represents a $28 million annual loss. When 1983 dollar prices are applied to that loss estimate, the annual loss comes to more than $100 million.

In 1981, a new system for predicting fusiform losses was established. This new method has several advantages: (1) it is computer based and compatible with data gathered by Forest Inventory

Figure 6. **Fusiform rust decision key.**



Management Options

1. Use seeds or seedlings that are resistant or less susceptible to disease.

Avoid planting rust-susceptible pines on high-hazard sites. Regeneration of high-hazard sites should be done with seeds or seedlings from:

- Rust-resistant slash and loblolly pine seed orchards or
- Less susceptible species (e.g., longleaf, shortleaf, and sand pines) or
- Geographic areas of resistance (e.g., Livingston Parish, LA; east Texas; Maryland; Arkansas) or a mixture of these. Use resistant local sources when possible.

2. Use protective fungicide treatments when economical.

Time the first fungicide treatment to coincide with development of telia on the oak leaves. Water and willow oaks are good indicators.

3. Cull seedlings with any obvious fusiform swellings on the stem.

Avoid movement of rust-infected stock from the nursery, or cull rust-infected seedlings before outplanting.

4. Reduce oak population when practical and when not in conflict with other management practices.

Consider using management techniques (e.g., hot summer burns before planting or herbicides) that reduce the amount of oak in or adjacent to pine plantings, nurseries, or seed orchards. Indiscriminate eradication of oak trees is not recommended, and careful attention should be given to the value of oaks for wildlife food and habitat, esthetics, and land values.

5. Modify fertilization practices.

On moderate- to high-hazard sites, fertilization (which predisposes pines to infection by promoting more succulent tissue) should be delayed until trees are 8 to 10 years old. Lethal fusiform rust infections after age 10 are rare.

On low-hazard sites, fertilization will not increased infection significantly, and increased growth will offset impact of infection.

Figure 6. **Fusiform rust decision key. Management options. —Continued**

6. Prune or excise fusiform galls and cankers.

From midsummer to midwinter, remove limbs with infections more than 3 inches (7.6 cm) and less than 18 inches (45.7 cm) from the bole. Treat stem infections and branch infections that are 3 inches or closer to the stem by removing the bark down to the wood, around the canker. Leave a margin of clear wood at least 1 inch (2.5 cm) on each side and 2 inches (5.1 cm) above and below the farthest extent of the canker.

Consider pruning forested stand if the practice would bring the stand up to adequate stocking.

Table A. **Adequate, marginal, and inadequate stocking for disease-free sapling and merchantable-sized stands of loblolly pine and slash pine[1,2]**

Degree of stocking	Sapling stands: Number disease-free stems per acre	Merchantable-sized stands: Ft^2 basal area of disease-free stems per acre
Adequate	300 +	60 +
Marginal	151-299	31-59
Inadequate	151	30

[1] Consideration of the number of disease-free stems, stocking level, and the average height and diameter of the plantation is essential in making management decisions. This table should be of assistance when deciding when fusiform rust, coupled with other factors, has reduced stocking to an unacceptable level.
[2] Plantations should be surveyed for fusiform damage 3 to 5 years after planting

7. Remove the most severely infected trees first when thinning. NOTE: Thinning can cause annosus root disease problems.

The higher the level of infection in a stand, the more important it is to thin selectively. Infected trees may be allowed to grow for up to 8 more years if less than 50 percent of the trunk circumference is cankered.

The following guidelines are recommended for stands that are old enough to thin commercially and that will have adequate stocking *(table A)* after the thinning operation:

- In stands with low levels of rust infection (less than 25 percent of trees with stem infections), remove the most severely stem-cankered trees first. Then remove less damaged trees to obtain a residual basal area of 75 to 85 square feet per acre (2.8 to 3.2 m^2/ha) for loblolly and 75 square feet per acre (2.8 m^2/ha) for slash pine.

- In stands with stem infections on 25 to 50 percent of the trees, thin by removing first the most severely cankered trees and then the less damaged trees.

For stands that will be inadequately stocked *(table A)* after thinning, regenerate the stand.

- If, for a heavily infected stand, the decision is not to regenerate but rather to thin, the high-risk trees should be removed. If access is a problem, consider removing every fifth row of trees in the plantation.

8. Consider seed tree or shelterwood regeneration.

When heavily infected stands must be eliminated and adequate numbers of disease-free trees are available, consider using a seed tree or shelterwood system to regenerate the stand. Seed trees, naturally selected, uninfected parent trees, may confer some genetic resistance on the future stand.

9. Consider increasing planting density.

Consider increasing planting density to compensate for the expected loss, particularly in high-hazard zones. This practice can be coupled with timely sanitation thinnings to remove trees with galls.

10. Regenerate stand or justify carrying to rotation understocked.

Evaluate 3 to 5 years after planting to determine if enough disease-free trees are present to maintain the stand to rotation age *(table A).* If disease-free stock is not adequate, regeneration can be accomplished by clearcutting and planting seedlings grown from a resistant seed source of loblolly and slash pines (management option 1) or by using seed tree or shelterwood regeneration where applicable (management option 8). If these infected stands are to be retained understocked because of wildlife benefits, excessive site preparation costs, or other reasons, consider thinning (management option 7).

11. Delay prescribed burning.

Prescribed burning in young infected stands should be avoided until the trees are at least 8 years old. In merchantable stands, prescribed burning should be performed after most fusiform stem-cankered trees have been removed in thinnings to prevent tree mortality or charcoal contamination of pulp.

and Analysis; (2) it can be modified easily, if necessary; and (3) it can be updated as new inventories are done. The system uses inventory data, such as species, age, and percent of living trees affected; growth and yield formulas; and other mathematical equations to estimate the cost of replanting and dollar losses of sawtimber and cordwood (table 4).

This fusiform rust loss assessment system has been used in Florida, Georgia, North Carolina, South Carolina, and Virginia, where fusiform kills about 24 million slash and loblolly pines each year. In 1983, the losses in the five States totaled about $31.4 million.

Prevention/Suppression

In the late 1970's, the prevention/suppression strategies for fusiform rust were condensed into a decision key (fig. 6). Following the chart, the manager will arrive at a set of numbers. These numbers refer to management options presented under the decision key. These management options are tailored to the site (Anderson and Mistretta 1982).

The USDA Forest Service, State forestry agencies, universities, consultants, and timber companies are using the decision key concept to varying degrees. In many cases, the key presented here has been modified to reflect localized conditions and management policies.

The decision key has also been incorporated into a computerized system that includes a number of pests and tree species. Using this computerized system, the manager can hazard rate a specific site for fusiform rust, obtain management options tailored to the site, and look at the economics of either planting loblolly or slash pines that have increased rust resistance or liquidating a heavily infested stand.

Outlook

Across the Southeast, the annual rate of fusiform rust infection has been climbing about 2 percent each year. Although sound management strategies are universally recognized as the most promising approach to slowing the current epidemic, the amount of infection and the area infested will continue to grow.

In the long term, as more genetically resistant material becomes available and management strategies are more effectively used, the tide is expected to

Table **4. Mortality and dollar losses attributed to fusiform rust in five States using the computerized loss assessment system—1983[1]**

Host/impact	Unit	State: Florida	Georgia	North Carolina	South Carolina	Virginia
Loblolly pine:						
Mortality	Dead trees	926,900	8,658,400	1,225,000	1,482,600	308,200
	Cubic feet	274,400	3,694,300	843,100	1,517,200	243,300
Cost of replanting	Dollars	268,400	1,465,960	103,598	676,600	0
Cordwood loss	Dollars	1,680,233	9,749,390	3,107,896	3,464,000	0
Sawtimber loss	Dollars	320,534	5,039,864	113,766	1,740,627	40,290
Total		**2,269,167**	**16,255,214**	**3,325,260**	**5,881,227**	**40,290**
Slash pine:						
Mortality	Dead trees	5,636,900	3,724,100	0	2,114,100	0
	Cubic feet	1,842,200	1,529,200	0	853,100	0
Cost of replanting	Dollars	74,200	66,045	0	0	0
Cordwood loss	Dollars	26,841	1,986,108	0	247,536	0
Sawtimber loss	Dollars	458,283	692,816	0	41,454	0
Total		**559,324**	**2,744,969**	**0**	**288,990**	**0**

[1]Dollar losses are estimated using growth and yield formulas and other mathematical equations.

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Figure 7. **Testing the resistance of loblolly pine seedlings to fusiform rust infection at the Resistance Screening Center.**

turn (Powers and others 1979). Many of these genetic selections are being made at the Resistance Screening Center, located in Asheville, NC. For 10 years, the center has selected genetically rust-resistant plant material for tree breeders. Each year, it screens between 500 to 1,000 seedlots to determine their relative resistance to fusiform rust (fig. 7). Tree improvement specialists use these data to select trees to place in their breeding programs, remove trees from orchards, and plant seedlings that are less susceptible to fusiform rust. One advantage is the relatively quick service the center can provide. Testing at the center takes about 1 year; field testing—where the fungus cannot be monitored or controlled—takes 5 years.

Because of its effects on the southern pine resource, fusiform rust is the most important forest disease of the Southeast. It will probably always be a serious management problem. But it is a problem that, in time, may be brought under control (Dinus and Schmidt 1977).

Nursery Pests

Pests May Cause 20 Percent of Seedling Mortality

Written by Steven W. Oak

Before the 1920's, managers let forests regenerate more or less naturally. Today, they exercise more control. In 1980, seedlings were planted over about 2.2 million acres (880,000 ha), an area equal to three times the size of Rhode Island. And the demand for seedlings is likely to continue, even increase (fig. 1).

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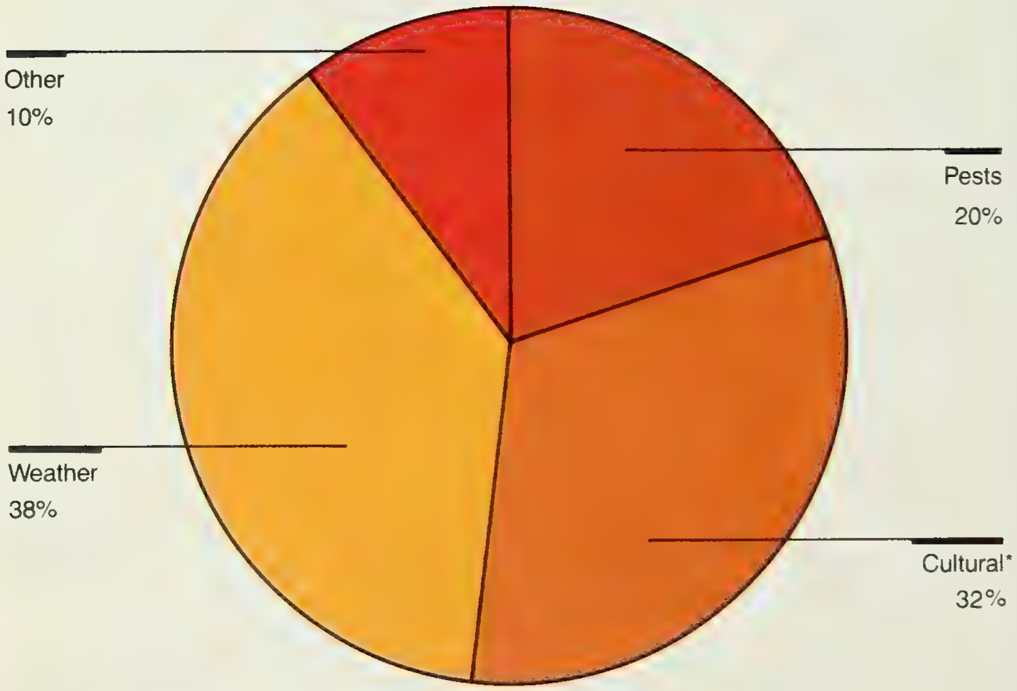
Figure 1. **Bundling bareroot stock to use in planting programs; USDA Forest Service Wind River Nursery in southwest Washington.**

Seedlings raised in forest nurseries are vulnerable to a number of agents. About 140 million seedlings growing in southern bareroot nurseries were killed during 1980. This mortality can be grouped into four causes: cultural practices; weather; a combination of other causes; and pests (Boyer and South 1984). Pests, according to the nursery managers' estimates, killed 28.4 million seedlings, about 20 percent of the seedlings killed during 1980 (fig. 2). An average-sized nursery in the region produces about 19.2 million seedlings annually; pest-caused losses undoubtedly limit the number of available seedlings.

Figure 2. **Mortality in southern bareroot nurseries by cause—1980**



Total: 140 million seedlings killed

*Includes nutrient deficiency, herbicides, weeds, weeding, and irrigation

Source: Chart based on data in article by J.N. Boyer and D.B. South entitled "Forest Nursery Practices in the South," Southern Journal of Applied Forestry, Volume 8, No. 2; 1984.

Historical Perspective

Many of the first nurseries were opened in 1924, after passage of the Clarke-McNary Act. These nurseries were established in the South, where farmland had been abandoned but was still able to support tree crops. Production exploded in the 1930's; more and larger nurseries were started to supply the activities of the newly formed Soil Conservation Service and the Civilian Conservation Corps. The Soil Bank Act of 1956 further stimulated nursery development (May 1980). Forest industry began to recognize the

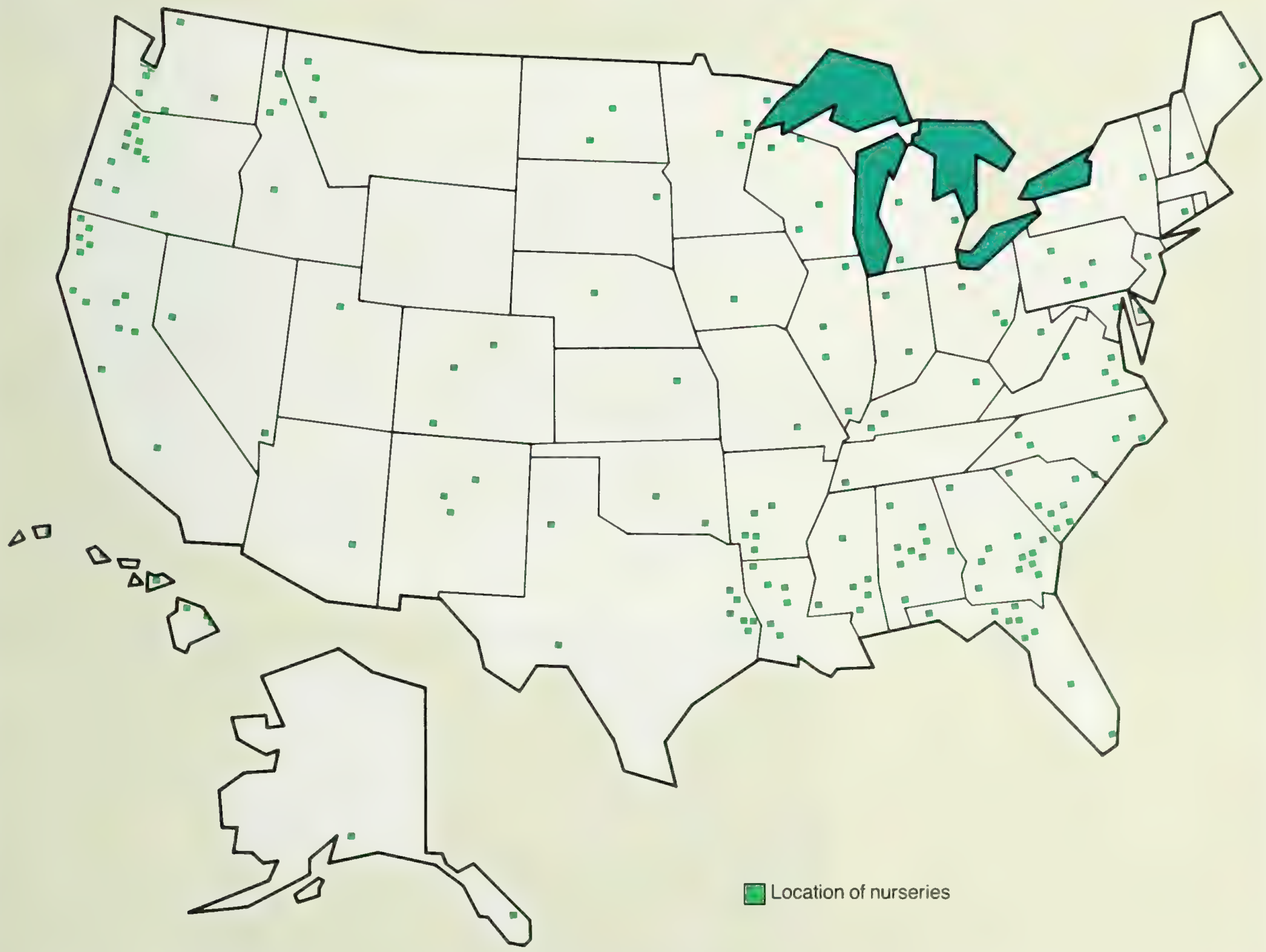
importance of reforestation and began to build their own nurseries.

Early pest management could rely on labor-intensive practices because labor costs were low and most nurseries were small. Hand weeding and removing dead and damaged seedlings from seedbeds were affordable management practices that reduced the risk of catastrophic pest outbreaks and subsequent losses. Pesticides, when used, were relatively nonspecific. Pest-damaged or otherwise inferior seedlings were culled before shipping, and seedlings were graded into quality classes. Today, nurseries are larger, and labor costs are higher. Although seedling grading and culling have nearly disappeared, managers are still practicing intensive pest management.

By 1980, about 40 percent of the forest nurseries were located in 13 Southeastern States (fig. 3). These southern nurseries supplied 1.25 billion seedlings, or 75 percent of the Nation's seedling needs (Cordell 1981). At the same time, just under half the acreage reforested in 1980 was located in the South.

In the South, the seedling crop grown on one acre—about three-fourths of a million seedlings—is worth between $15,000 and $20,000. Without good pest

***Figure 3.* Location of major forest nurseries in the United States in 1980. In the South, a little over half of the nurseries are privately owned by forest industry; the States operate the remainder, except for one nursery that is Federally operated. Outside the South, a much larger proportion of the nurseries are run by State and Federal agencies.**



Source: Map based on information in the "1981 Directory of Forest Tree Nurseries in the United States," published by the American Association of Nurserymen in cooperation with the USDA Forest Service.

management, an entire crop could be lost. The cost of such a catastrophe in a single nursery could reach $500,000.

Pest-Caused Seedling Losses

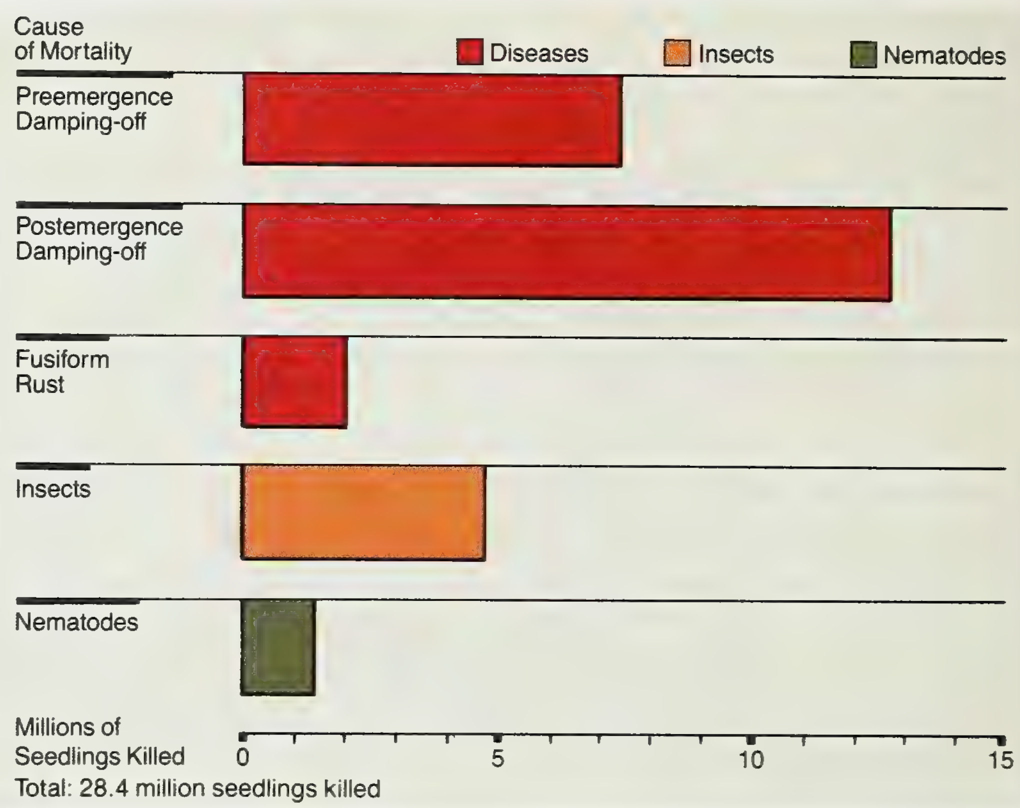
A successful planting program depends on the availability of reasonably priced, high-quality seedlings. Many diseases cause damage that results in undersized or otherwise poor-quality seedlings that must be discarded. More insidious and costly are cases where infection goes undetected in the nursery, only to damage or kill the seedlings later, after they are planted on a site.

Tracing the exact cause of losses attributed to nursery pests is seldom simple. Pests are part of a complex of environmental conditions; two or more types of pests can occur simultaneously.

Pest-caused losses are usually attributed to diseases, insects, and nematodes. In 1980, nematodes and insects killed about one-fifth of the seedlings lost. Nematodes are ubiquitous, parasitic root pests that damage nearly all tree species. Insects that damage nursery stock include tip moths on southern pines, cutworms on most conifer species, and white grubs on the roots of conifers and hardwoods. Diseases, however, especially preemergence damping-off, postemergence damping-off, and fusiform rust, accounted for most of the damage (fig. 4) (Boyer and South 1984).

Diseases of tree seedlings are caused by many agents, both nonliving and living. Nonliving, or abiotic, agents include waterlogging, chemical injuries, soil compaction, and weather-related injuries, such as heat lesions or frost damage. Biotic causes include fungi, as well as viruses, bacteria, and other plants. Soilborne fungi are some of the most seriously damaging of all nursery pests. They most often attack roots, but all plant parts may become infected. Because of the complexity of soil, soilborne fungi are also the most difficult to control economically.

Figure 4. **Chronic, pest-caused mortality in southern nurseries—1980.**



Source: Chart based on data in article by J.N. Boyer and D.B. South entitled "Forest Nursery Practices in the South," Southern Journal of Applied Forestry, Volume 8, No. 2; 1984.

The major diseases of forest nurseries can be grouped into the following categories: damping-off, root diseases, stem rusts, stem and shoot diseases, and foliage diseases (table 1).

Damping-off. More than two-thirds of the chronic pest-caused losses in nurseries are attributed to damping-off. Nearly all tree species are affected, nationwide. The fungi that cause damping-off can attack either the germinating seed before it emerges or the very young seedling. When postemergence damping-off occurs, the stem of the young seedling withers, and the seedling topples over (fig. 5).

Root Diseases. Charcoal rot decays the roots of conifers grown in the South and West. Other root rots damage hardwoods, such as black walnut,

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Figure 5. **Postemergence damping-off of conifer seedling in Asheville, NC, nursery.**

Table 1. **Common nursery diseases, causal agents, and host species**

Common name	Causal agent	Host/range
Damping-off	*Fusarium.* spp. *Pythium* spp. *Phytophthora* spp. *Rhizoctonia* spp.	Most conifer and hardwood species nationwide
Root diseases		
Charcoal rot	*Macrophomina phaseolina*	Many conifer species in South and West
Other root rots	*Phytophtora* spp. *Cylindrocladium* spp.	Many hardwood and conifer species in South and East
Stem rusts		
Fusiform rust	*Cronartium quercuum* f. sp. *fusiforme*	Southern pines, especially slash and loblolly
Eastern gall rust	*Cronartium quercuum* f. sp. *quercuum*	Hard pines in East and South
Western gall rust	*Endocronartium harknessii*	Hard pines from Lake States westward
Stem and shoot diseases		
Phomopsis blight	*Phomopsis* spp.	Junipers from Great Plains eastward
Sirococcus tip blight	*Sirococcus strobilinus*	Many western conifers
Stem and shoot cankers	*Septoria* spp., *Phomopsis* spp., *Cytospora* spp., *Fusarium* spp.	Many hardwood species, especially poplars
Foliage diseases		
Brown spot	*Schirrhia acicola*	Longleaf pine in South
Lophodermium needle blight	*Lophodermium pinastri*	Many pine species, especially in East
Gray mold	*Botrytis cinerea*	Many conifers grown in greenhouses, especially in West
Anthracnose	*Gnomonia* spp., *Gleosporium* spp., *Glomerella* spp.	Many eastern hardwoods, especially black walnut and sycamore

yellow poplar, and sweetgum, and conifers, such as sand pine, eastern white pine, and red pine (fig. 6).

Stem Rust. Rusts can cause catastrophic losses in some localities. In southern nurseries, fusiform rust is particularly damaging on loblolly and slash pines.

Eastern and western gall rusts infect jack pine in the Lake States. Further west, they infect jack, lodgepole, Scotch, and other hard pines.

Stem and Shoot Diseases. Seedlings infected with stem and shoot diseases typically are smaller than healthy seedlings or may have forked stems. Phomopsis blight is especially damaging to eastern redcedar and other junipers in the East and to other conifers nationwide. Sirococcus tip blight damages many western conifers, especially Jeffrey, ponderosa, and lodgepole pines. In some Lake States nurseries,

sirococcus tip blight also damages jack pine.

Hardwoods, particularly poplars and cottonwood, are susceptible to various stem and shoot canker diseases.

Foliage Diseases. The principal foliage disease in the South is brown spot needle blight on longleaf pine. From the Lake States east to New England and the Middle Atlantic States, lophodermium needle blight damages red, Scotch, and eastern white pines. Gray mold is a serious problem on container-grown western conifers. Other fungi cause anthracnose diseases on most hardwood species; sycamore and black walnut are most commonly affected.

Resources Affected

Forests are under increasing pressure to provide for more varied uses, often on the same site. Planting seedlings is one way to establish the desired trees. In contrast to letting a site regenerate itself naturally, planting trees gives managers control over the species composition and density and the time required to produce the desired result. Seedlings are also used on sites difficult to regenerate naturally, such as the degraded soils of old mining sites.

Nursery pests limit the number of seedlings available for reforestation and reclamation purposes. When supplies are limited, timber, recreation, wildlife, and water resource management objectives must be compromised.

Pest Status From 1979 to 1983

Chronic losses tend to occur at relatively low levels in all nurseries; records of these losses are not normally maintained by individual nurseries or States. These chronic losses are punctuated by instances of extensive, random damage from pest outbreaks associated with such factors as the environment or nursery cultural practices. The losses presented in table 2 are, for the most part, instances of this random, unpredictable kind of damage. According to table 2, losses averaged 37.3 million seedlings annually between 1979 and 1983.

Although records are not usually kept of chronic losses, these types of losses are significant. In 1980, for example, chronic losses in southern nurseries totaled about 28.4 million seedlings. If the rate of chronic losses in southern nurseries is extrapolated to the rest of the country and these estimates added to the average of 37.3 million seedlings from table 2, annual losses double. The total projected loss—75 million seed-

Table 2. **Pest-caused losses for both conifers and hardwoods in forest nurseries in the United States from 1979 to 1983**[1]

State	Condition and causal agent	1979	1980	1981	1982	1983
		Thousands of seedlings killed or unusable				
Alabama	Root disease *Macrophomina phaseolina*	5,100	0	10	0	0
Alaska	None reported	0	0	0	0	0
Arizona	None reported	0	0	0	0	0
Arkansas	Stem and shoot disease *Phomopsis* spp.	50	0	0	0	0
California	Damping-off *Fusarium oxysporum*	466	618	623	890	626
	Root disease *Fusarium oxysporum* *Phytophthora cinnamomi*	94	69	633	709	540
	Stem and shoot disease *Phomopsis* spp. *Sirococcus strobilinus*	1,052	894	683	732	488
	Foliage disease *Phoma* sp. *Botrytis cinerea*	3,132	3,832	603	1,468	3,310
Colorado	Damping-off *Pythium-Fusarium* spp. complex	0	0	500	100	0

[1]See footnote at end of table.

Table 2. **Pest-caused losses for both conifers and hardwoods in forest nurseries in the United States from 1979 to 1983—Continued**

State	Condition and causal agent	1979	1980	1981	1982	1983
		Thousands of seedlings killed or unusable				
	Root disease *Fusarium* sp.	0	0	140	0	0
	Stem and shoot disease *Sirococcus strobilinus*	0	0	0	0	10
	Foliage disease *Botrytis cinerea*	0	0	50	0	0
	Insect *Phoeosinus* sp. Fungus gnat (unknown sp.)	50	0	0	10	0
	Miscellaneous conditions Slugs, Improper storage	0	0	175	0	0
Connecticut	None reported	0	0	0	0	0
Delaware	None reported	0	0	0	0	0
Florida	Root disease *Phytophthora cinnamomi* *Meloidogyne incognita* - *Macrophomina phaseolina* complex *Pythium* sp.	400	0	180	0	38
	Stem rust *Cronartium quercuum* f. sp. *fusiforme*	7,500	0	5,500	0	0
	Stem and shoot disease *Fusarium moniliforme* var. *subglutinans* *Phomopsis* spp. *Cylindrocladium scoparium*	265	0	0	75	700
	Foliage disease *Rhizoctonia* sp.	120	75	110	0	750
Georgia	Root disease *Phytophthora cinnamomi*	0	50	0	0	0
	Miscellaneous conditions Herbicide injury	0	500	0	0	0
Hawaii	None reported	0	0	0	0	0
Idaho	Root disease *Fusarium* spp. *Fusarium-Pythium* spp. complex *Phoma* sp.	152	101	92	106	80
	Stem and shoot disease *Sirococcus strobilinus* *Diplodia pinea*	0	0	150	180	125
	Foliage disease *Meria laricis* *Botrytis cinera*	70	60	65	90	1,070
	Insect Cranberry girdler moth Pyralid moth (unknown sp.)	0	0	12	302	132
	Miscellaneous conditions Sand blasting damage	0	0	0	0	239

Table 2. **Pest-caused losses for both conifers and hardwoods in forest nurseries in the United States from 1979 to 1983—Continued**

State	Condition and causal agent	1979	1980	1981	1982	1983
		Thousands of seedlings killed or unusable				
Illinois	None reported	0	0	0	0	0
Indiana	Damping-off Fungus complex	0	0	0	0	83
	Root disease *Phytophthora* sp.	0	12	9	4	5
	Stem and shoot disease *Botrydiplodia theobromae* *Diplodia pinea* *Phomopsis eleagni*	75	99	0	0	4
	Foliage disease *Xanthomonas juglandis* *Gnomonia* spp. Leaf spot (unknown sp.) Downy mildew (unknown sp.)	0	5	0	21	55
	Miscellaneous conditions Winter kill Storage mold	93	21	0	115	20
Iowa	Foliage disease *Herpobasidion deformans*	0	0	0	225	250
Kansas	Stem and shoot disease *Rhizoctonia* sp. *Alternaria-Phomopsis-Cytospora-Verticillium* spp. complex	60	50	0	0	0
Kentucky	Damping-off *Phytophthora parasitica*	0	0	400	0	0
	Root disease *Phytophthora citricola-P. cinnamomi* complex	425	25	25	50	25
	Miscellaneous conditions Herbicide injury	200	350	300	200	250
Louisiana	Damping-off *Fusarium* spp.	0	100	100	0	0
	Root disease *Pythium* spp.	0	0	0	50	0
	Stem rust *Cronartium quercuum* f. sp. *fusiforme*	0	500	0	0	0
	Stem and shoot disease *Phomopsis* spp.	0	0	0	50	10
	Insect Cutworms (unknown sp.)	0	0	10	0	0
Maine	None reported	0	0	0	0	0
Maryland	Miscellaneous conditions Birds, Voles	6	6	6	6	6
Michigan	Stem rust *Cronartium quercuum* *Endocronartium harknessii*	0	83	83	83	30
	Stem and shoot disease *Diplodia pinea*	150	200	500	333	66

Table 2. **Pest-caused losses for both conifers and hardwoods in forest nurseries in the United States from 1979 to 1983—Continued**

State	Condition and causal agent	1979	1980	1981	1982	1983
		Thousands of seedlings killed or unusable				
	Foliage disease *Lophodermium pinastri*	0	0	1,115	115	333
	Miscellaneous conditions Stunting (cause unknown)	106	130	170	211	196
Minnesota	Stem rust *Cronartium quercuum* f. sp. *quercuum* *Endocronartium harknessii*	0	83	83	83	30
	Stem and shoot disease *Diplodia pinea*	150	200	500	333	66
	Foliage disease *Lophodermium pinastri* *Herpobasidion deformans*	0	0	1,115	340	583
	Miscellaneous conditions Arsenic toxicity Stunting (cause unknown)	106	130	170	411	466
Mississippi	Stem and shoot disease *Phomopsis* spp.	140	50	0	60	0
	Foliage disease Blight (cause unknown)	0	0	0	10	40
	Miscellaneous conditions Lack of dormancy	0	0	0	441	0
Missouri	None reported	0	0	0	0	0
Montana	Root disease *Fusarium-Pythium* spp. complex	10	10	10	10	10
	Foliage disease *Botrytis cinerea*	0	0	60	60	60
Nebraska	Root disease *Fusarium* sp.	0	0	0	0	10
	Stem and shoot disease *Phoma* sp. *Phoma* sp.-frost complex *Diplodia pinea* *Phomopsis* sp.	30	50	10	50	0
	Foliage disease *Coccomyces* sp. *Alternaria-Phyllosticta* spp. complex	10	10	0	10	10
	Insect Grasshoppers (unknown sp.) *Rhyaciona* sp. *Nephrotoma sodalis*	0	0	0	30	0
	Miscellaneous conditions Frost	0	0	0	0	0
Nevada	Root disease Unknown cause	0	0	0	0	42
New Hampshire	None reported	0	0	0	0	0
New Jersey	None reported	0	0	0	0	0

Table 2. **Pest-caused losses for both conifers and hardwoods in forest nurseries in the United States from 1979 to 1983—Continued**

State	Condition and causal agent	1979	1980	1981	1982	1983
		Thousands of seedlings killed or unusable				
New Mexico	Damping-off *Fusarium-Pythium* spp. soil conditions complex	0	0	0	0	1,000
New York	Damping-off *Fusarium oxysporum* *Pythium* sp. *Phytophthora* sp.	250	250	250	5,000	5,000
	Foliage disease *Lophodermium pinastri*	0	0	0	1,000	0
North Carolina	Root disease *Cylindrocladium floridanum* *Cylindrocladium crotalariae* *Phytophthora citricola-Cylindrocladium crotalariae* complex	100	0	125	0	0
North Dakota	None reported	0	0	0	0	0
Ohio	None reported	0	0	0	0	0
Oklahoma	Stem and shoot disease *Diplodia* spp.	0	0	0	10	0
	Foliage disease *Gnomonia leptostyla*	0	50	0	0	0
Oregon	Damping-off *Pythium* spp. *Fusarium* spp.	2,000	1,750	2,250	2,250	2,500
	Root disease *Phytophthora* spp. *Fusarium oxysporum*	500	557	553	550	550
	Foliage disease *Botrytis cinerea* *Dothistroma pini* *Rosellinia herpotrichoides*	3,500	3,500	3,500	3,510	3,511
	Stem and shoot disease *Phoma-Fusarium* spp. complex *Sirococcus strobilinus* *Fusarium roseum*	203	503	5,503	7,503	2,603
Pennsylvania	Root disease *Cylindrocladium* sp. *Fusarium roseum*	0	0	0	0	40
	Miscellaneous conditions Soil physical factors	101	101	1	12	6
South Carolina	Root disease *Cylindrocladium scoparium* *Phytophthora citricola* *Macrophomina phaseolina*	0	1,050	50	50	0
	Stem and shoot disease *Phomopsis* spp.	50	100	100	50	0
	Insect Cutworm (unknown sp.)	0	0	0	50	0
South Dakota	Root disease *Agrobacterium tumefaciens*	0	0	10	0	0

Table 2. **Pest-caused losses for both conifers and hardwoods in forest nurseries in the United States from 1979 to 1983—Continued**

State	Condition and causal agent	1979	1980	1981	1982	1983
		Thousands of seedlings killed or unusable				
	Foliage disease *Botrytis cinerea* Powdery mildew (unknown sp.)	0	0	10	0	10
	Insect Aphids (unknown sp.)	0	0	0	0	20
Tennessee	Damping-off *Fusarium* spp.-herbicide injury complex	0	0	0	1,500	0
	Root disease *Phytophthora citricola*	0	0	50	0	0
	Miscellaneous conditions Nutrients/soil physical factors/weather complex	250	250	250	250	250
Texas	Root disease *Macrophomina phaseolina* *Fusarium* spp.	0	0	0	60	0
	Stem and shoot disease *Phomopsis* spp.	20	0	0	50	0
Utah	Damping-off *Fusarium* sp.	20	0	0	0	0
	Stem and shoot disease *Cytospora* sp.	0	50	0	0	0
	Insect *Bradysia* sp.	0	0	0	7	6
	Miscellaneous conditions Rodents, gophers	0	50	0	30	0
Vermont	None reported	0	0	0	0	0
Virginia	Miscellaneous conditions Hail	0	0	0	0	8,000
Washington	Damping-off *Pythium* spp. *Fusarium* spp.	2,500	2,250	2,750	2,750	3,000
	Root disease *Phytophthora* spp. *Fusarium oxysporum*	500	557	553	550	550
	Stem and shoot disease *Phoma-Fusarium* spp. complex *Sirococcus strobilinus*	3	3	5,003	2,503	2,503
	Foliage disease *Botrytis cinerea* *Meria laricis*	3,500	3,550	3,625	3,510	3,510
Wisconsin	Root disease *Cylindrocladium* spp. unknown cause	1,000	1,000	800	50	100
	Stem rust *Cronartium quercuum* f. sp. *quercuum* *Endocronartium harknessii*	0	83	83	83	30
	Stem and shoot disease *Diplodia pinea*	150	200	500	333	66

Table 2. **Pest-caused losses for both conifers and hardwoods in forest nurseries in the United States from 1979 to 1983—Continued**

State	Condition and causal agent	1979	1980	1981	1982	1983
		Thousands of seedlings killed or unusable				
	Foliage disease *Lophodermium pinastri*	0	0	1,115	115	333
	Insect Cutworm (*Feltia ducens*)	1,000	0	0	0	0
	Miscellaneous conditions Stunting (cause unknown)	106	130	170	211	196
West Virginia	Root disease *Cylindrocladium* sp.	97	92	52	45	94
	Insect Pine sawfly (*Neodiprion lecontei*)	0	1	0	0	0
	Miscellaneous conditions Hail	0	0	0	350	0
Total		**35,862**	**24,390**	**41,495**	**40,345**	**44,636**

[1]Massachusetts, Rhode Island, and Wyoming have no nurseries.

lings—is enough to reforest 167,000 acres (67,600 ha) at a density of 450 stems per acre.

From 1979 to 1983, soilborne pests, particularly damping-off and root diseases, caused most of the chronic and random losses. Insect-caused damage also remained less important than disease-caused damage. Insect damage was usually confined to small numbers of seedlings in scattered nurseries.

Prevention/Suppression

In bareroot tree nurseries, one of the most widely used methods of controlling pest losses is by fumigating the soil with methyl bromide-chloropicrin formulations before seeds are planted (fig. 7). When properly done, this technique reduces most of the soil fungi, insects, nematodes, and weed seeds to innocuous levels. Beneficial organisms are also eliminated, but they are usually present nearby and generally return more quickly than harmful organisms.

Recently, solar pasteurization has been used on a limited scale as an alternative to fumigation. Solar pasteurization eliminates some of the less persistent soil pests. During pasteurization, the sun's heat partially sterilizes the soil.

Although broad-spectrum protective fungicides are widely used, specialized compounds have recently been developed. These specialized chemicals are more effective against their target pests than broad-spectrum compounds. During 1979–80, triadimefon, a

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Figure 6. **Sweetgum seedlings (foreground) in a South Carolina nursery damaged by cylindrocladium root rot.**

specialized compound, was registered for control of fusiform rust. Usually, only three or four applications are required each year. Ferbam, the broad-spectrum fungicide used before triadimefon was registered for use in nurseries, required 5 to 10 times more frequent applications and produced variable results.

Other methods control pests less directly. Planting cover crops that are not common hosts for nursery pests is one example. Adding organic matter amendments, such as pine bark, sawdust, or peat, to the soil often results in better seedling quality, which, in turn, contributes to a seedling's ability to resist damage. These amendments may also contain beneficial micro-organisms that compete with seedling pests or even parasitize them.

The manipulation of symbiotic fungus-root associations, or mycorrhizae, has become practical in nurseries that grow seedlings to plant on harsh reforestation sites, such as mine spoils. In the South and East, some nurseries are inoculating their seedbeds with *Pisolithus tinctorius*, one such mycorrhizal fungus. Mycorrhizal root systems make the roots more efficient at extracting nutrients and moisture and can also protect roots from environmental extremes and certain root pathogens.

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Figure 7. Fumigating with methyl bromide-chloropicrin in Early County, GA. The fumigant in the tanks is injected into the soil and the soil covered with a polyethylene tarp (background), which is quickly sealed to prevent the gas fumigant from dissipating.

F-705660

Figure 8. Artificial regeneration in Caldwell County, NC

Outlook

Advancements in biological control methods, especially those that fight soilborne pests, can be expected. Manipulation of micro-organisms competitive with or parasitic on pathogens could become routine. Methods for using other mycorrhizal fungi may also be developed. The more specialized mycorrhizae would make seedlings better adapted to specific problem sites.

Planting is likely to continue and possibly increase (fig. 8). The demand for planting stock is increasing in California, Oregon, Washington, Idaho, and Montana. Seedling demand in the South will continue to exceed demand in other parts of the country.

Because of the great demand for trees, pressure will increase to produce more and better seedlings. Increased production will probably have to come from the existing nurseries because building new nurseries costs a great deal of money. And pest losses will continue. These losses may be greater in Federal and State nurseries than in privately owned, industrial nurseries, many of which have recently acquired new land and more specialized equipment and improved their facilities. Experience has shown that pest losses are usually higher and seedling quality lower in nurseries that have a longer production history. Finally, more intensive management of nurseries will be needed. High demand makes imperative the control of losses from all causes, including pests.

Root Diseases

Will We Be Able To Control Their Spread?

Written by Gregg A. DeNitto

We are managing our forests more intensively; as a result, root diseases are becoming a national problem. The incidence of root disease often relates to the amount of human activity in forest stands. So when we harvest timber from infected stands or open up new areas to timber production, we can simultaneously increase root diseases and the damage they cause.

What happens when a tree becomes infected? That depends. Some root diseases kill the host tree quickly. Others slow its growth, decaying the wood in the roots and, sometimes, the wood in the lower trunk. As the wood decays, the tree is robbed of its water, nutrients, and structural support. Eventually, the weakened tree dies or topples over. By weakening trees, root diseases predispose the trees to attacks by other pests. And some of the fungi that cause root diseases can remain alive long after the host tree dies and thus are transmitted to each new generation.

This group of diseases attacks most of the commercial tree species in the United States. In some areas of Oregon and Washington, for example, USDA Forest Service plant pathologists estimate that 5 percent of formerly productive forest land can no longer produce timber.

Major Root Diseases

Although root diseases are found nationwide, their effects are more significant in certain geographic areas and forest types. In the West, California, Oregon, Washington, Idaho, and Montana experience the greatest amount of root disease damage. The damage is primarily caused by annosus root disease, armillaria root disease, black stain root disease, laminated root rot, and red-brown butt rot. In the pine plantations of the South, annosus root disease and littleleaf disease are problems (table 1). These six root diseases produce most of the root disease-related losses.

- Although the causal fungus infects trees nationwide, annosus root disease is only a problem in some parts of the South and West. In resinous species, such as loblolly and ponderosa pines, it grows in the wood-bark interface and spreads between trees through root contact; expanding root disease centers of dead and dying trees develop.

- Like annosus root disease, armillaria root disease infects woody plants in all parts of the country. Armillaria usually infects

Table 1. **Root diseases causing most of the losses in the United States**

Disease	Causal fungus	Areas where management concern	Commercially important hosts
Annosus root disease	*Heterobasidion annosum* (Fr.) Bref.	South, West	All conifers, especially pines, hemlock, and true firs
Armillaria root disease	*Armillaria mellea* (Vahl: Fr.) Kumm.	West	All woody species
Black stain root disease	*Ceratocystis wageneri* Goheen & Cobb	West	Douglas-fir, ponderosa pine, pinyon pine
Red-brown butt rot	*Phaeolus schweinitzii* (Fr.) Pat.	Idaho, western Montana, Wyoming	Douglas-fir,
Laminated root rot	*Phellinus weirii* (Murr.) Gilbertson	Oregon, Washington, northern Idaho	Douglas-fir white fir, grand fir, Pacific silver fir, mountain hemlock, western redcedar
Littleleaf disease	*Phytophthora cinnamomi* Rands and causal complex	Southeast	Shortleaf pine, loblolly pine

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Figure 1. Cross section of Douglas-fir in Willamette National Forest, OR. Red-brown butt rot has decayed the bole.

stressed trees, that is, trees weakened by factors such as drought, defoliation, root damage, or other pests. Its effects depend upon the geographic location, host species, age of the host, and stand and site conditions. The disease can kill a tree rapidly or can cause a gradual decline through associated root and butt decay.

- Red-brown butt rot is common throughout the West, especially in Douglas-fir. The causal fungus primarily decays the heartwood of roots and the lower trunk (fig. 1), often causing the tree to be toppled by the wind.

- Laminated root rot affects Douglas-fir, true firs, mountain hemlock, and western redcedar in the Pacific Northwest. The fungus that causes the root rot survives for decades in roots and stumps. Consequently, any new growth also becomes infected; thus, the level of inoculum on a site increases.

- Littleleaf disease affects shortleaf and loblolly pines in the Piedmont area of the South. The disease results from the interac-

F-705662

Figure 2. Black stain root disease infection on Douglas-fir. The dark staining of the wood is symptomatic of infection.

tion of soil and nutrient conditions and a fungus that decays the small feeder roots.

- Black stain root disease plugs the vessels that transport water and nutrients from the roots, inducing a vascular wilt-type disease (fig. 2). Although found throughout the West, the disease interferes with management only in certain forest stands.

Several other root diseases, listed in table 2, are important locally but are not as significant nationally as those previously discussed.

Table 2. **Root diseases of local significance**

Disease	Causal fungus	Range	Host(s)
Ohia decline	*Phytophthora cinnamomi* Rands	Hawaii	Ohia
Port-Orford-cedar root disease	*Phytophthora lateralis* Tuck. & J.A. Milb.	Southwestern Oregon and northwestern California	Port-Orford-cedar
Red root and butt rot	*Inonotus tomentosus* (Fr.) S.C. Teng	Central Idaho and southern Utah	Spruces, true firs, Douglas-fir
Sand pine root disease	Complex of fungi	Florida, Alabama, Georgia, and South Carolina	Sand pine
White pine root decline	*Verticicladiella procera* Kend.	Eastern United States	Eastern white pine
White pocket rot	*Inonotus circinatus* (Fr.) Gilbertson	Southeastern United States	Southern yellow pines
Yellow cedar dieback	Unknown	Southeastern Alaska	Alaska yellow cedar

Historical Perspective

Root diseases have long been recognized as causes of tree mortality. Within the past three decades, both pest managers and foresters have begun to realize that root diseases are also part of pest complexes—mortality often results from the interaction of insects and diseases. One of the principal interactions is that of root diseases and bark beetles. A substantial amount of bark beetle-related mortality nationwide, for example, is the direct result of annosus root disease.

Previous bark beetle control efforts that failed to consider the presence of root diseases in an area were generally minimally successful. Managers now realize that when they develop control methodologies, they need to consider both pests—root diseases and bark beetles.

Resources Affected

The damage caused by root diseases depends on the host, on stand and site conditions, and on the disease itself. The damage includes tree death, growth reduction, wood decay, windthrow, and increased susceptibility to successful attack by other pests.

Timber. Root diseases reduce volume yields. Wood is lost when trees die or are windthrown and cannot be recovered. If accessible, however, these dead trees can be salvaged for lumber, pulpwood, or firewood. Because some root diseases limit the tree's growth, productivity may also be reduced.

Consequently, root diseases may lower economic returns. Projected intermediate cuttings are canceled before the final harvest, rotation ages need to be changed, and decay results in reduced volume. In all, timber management costs more. Root disease fungi can also persist in roots and stumps for many years, infecting new growth long after the original stand has been removed.

Recreation. Root diseases have two primary effects on recreation. First, dead trees open the forest canopy and, therefore, may alter the pattern of recreational use (fig. 3). Depending on the size of the infected area, this effect may be limited to individual camping sites or extend over entire campgrounds. Also, root-rotted trees, which are likely to topple, present a hazard to people, their property, and physical improvements such as tables, benches, and buildings (fig. 4).

Wildlife. How managers assess the effects of root diseases depends on their objectives for an area. Root diseases create small openings in forests—openings that often regenerate with brush and herbaceous species. Certain wildlife species, such as deer and elk, feed on this new vegetation and find cover in the nearby forest.

In addition, dead standing trees within these openings can

F-705663

Figure 3. Trees killed by annosus root disease have been removed from this campground in the San Bernardino National Forest, CA, creating an open area.

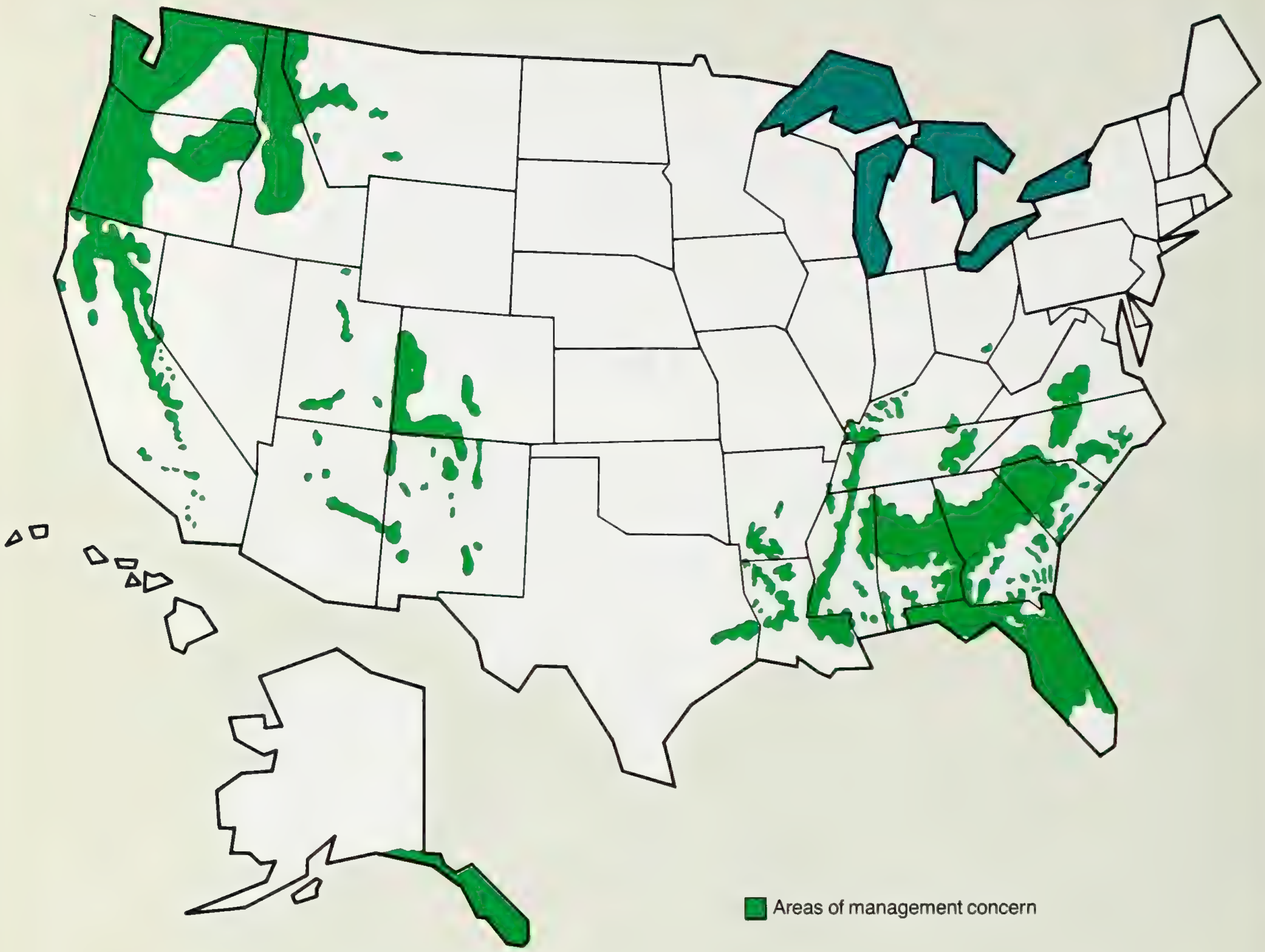
F-705664

Figure 4. A root-diseased sugar pine destroyed this forest cabin in Sequoia-Kings Canyon National Parks, CA.

F-705665

Figure 5. This large opening in pinyon pine on the San Bernardino National Forest, CA, is the result of black stain root disease.

Figure 6. **Areas where root diseases are a management consideration.**



benefit snag-dependent species. Because their roots are decayed, however, snags may soon topple. In old-growth forests, root diseases can break up stand structure and possibly adversely affect wildlife dependent on old growth.

Fire. Dead trees and large accumulations of woody debris can increase the potential danger of fire. In root disease centers, windthrown trees may also have a "fire-ladder" effect, carrying fire from the ground level into the crowns of living trees.

Visual Quality. Generally, root diseases produce small openings in forests. In some situations, however, these openings may coalesce to cover 100 acres (40 ha) or more (fig. 5). When they are visible from well-traveled roads, these large openings can affect people's enjoyment of the view.

Status From 1979 to 1983

Over large areas, root disease incidence remains relatively constant in the short term; therefore, the acreages in table 3 represent an estimate for any year from 1979 to 1983. These figures include areas on lands of all ownerships—private, State, and Federal—where root diseases warrant special management consideration.

The figures were derived from a variety of surveys done by pest management specialists during the past decade. The surveys ranged from large, multiple-forest

ownership surveys to small, single-stand evaluations. In some cases, considerable extrapolation was needed to arrive at the figures.

The areas of management consideration in figure 6 represent areas where the host species are present and where observations indicate that a particular root disease is or may become a problem if improper management actions are taken. Because of its scale, the map shows these areas in a very general way, so the total area depicted sometimes looks larger than the number of acres listed in table 3.

In contrast to the relatively static range of root diseases, root disease-related mortality may vary from year to year, influenced by environmental conditions, such as soil moisture. The additional stress from drought, for example, may kill trees already stressed by root disease.

The volumes in table 3, however, are best estimates of average annual mortality during the 5-year period. Because the same areas are not surveyed each year, it was impossible to provide yearly estimates.

The volume estimates in table 3 are also conservative. They include only the volume of mortality related to root diseases—not the volume of growth reduction and decay caused by root diseases. We need further information on growth reduction and decay to make reasonable estimates. Also, because of insufficient survey information, mortality estimates for some diseases and from some States were not available. Another factor reducing the estimates is the below-ground nature of root diseases. During mortality surveys, which are the basis of many of these data, it is

Table 3. **Acres on all ownerships where root diseases are a management concern and the average annual root disease-related mortality from 1979 to 1983**

Region/State	Area of management concern	Volume of mortality
	Acres	1,000 cubic feet
Pacific States:		
Alaska	24,000	—[1]
California	8,132,500	19,398
Hawaii	700	—
Oregon	1,221,000	75,776
Washington	999,000	56,155
Rocky Mountain States:		
Arizona	281,600	2,107
Colorado[2]	38,400	127
Idaho	1,929,000	41,210
Montana	1,400,000	40,000
Nevada	500	25
New Mexico	858,700	2,653
Utah	50,000	950
Wyoming	5,500	105
Eastern States[3]:		
Alabama	228,500	—
Florida	456,800	4,113
Georgia	587,800	1
Kentucky	13,400	—
Mississippi	8,900	—
North Carolina	184,700	—
Ohio	1,500	—
South Carolina	204,100	—
Tennessee	40,700	—
Virginia	138,000	—
Total	**16,805,300**	**242,620**

[1] — indicates no information available.
[2] Area and volume for subalpine fir in spruce–fir type only.
[3] Acreage data for the Eastern States, except Ohio, are for littleleaf and sand pine root diseases only. Volume of mortality is also for sand pine root disease only.

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Figure 7. **Applying borax to a freshly cut stump in Lassen National Forest, CA.**

difficult to examine the root system for pathogens. Only when the causal fungi are at or near the ground line can they be detected and included as causal agents.

Prevention/Suppression

Overall forest productivity will be highest in healthy stands. Consequently, it is better to prevent fungi from infecting a stand than to change the way stands are managed once an area becomes infected.

Prevention efforts are aimed at reducing the probability of root disease organisms infecting healthy trees. For instance, several fungi enter stands primarily by infecting freshly cut stumps. In the past decade, the use of stump protectants has increased during harvesting activities. Most notably, borax or the fungus *Phlebia gigantea* (Fr.) Donk is used to reduce the spread of annosus root disease (fig. 7). Other activities to reduce the amount of stump infection include restricting logging to specific seasons and, in areas of very high value, removing stumps and roots.

Fungi also enter healthy trees through wounds on the lower trunk and roots. In forest stands,

reducing these injuries during harvesting activities will help reduce infection. Another method of reducing wounding is to reduce the number of times harvesting activities take place in a stand. The number of harvests can be reduced by increasing the spacing between seedlings in regenerated areas and by increasing the spacing between residual trees during any subsequent thinnings. In recreation areas, proper planning of construction activities and site layouts can reduce tree wounding.

Once established, root diseases are generally difficult and expensive to control. The fungi that live in stumps and roots, for example, survive to infect the next generation of host trees. For this reason, harvesting alone will rarely solve the problem.

When a stand becomes infected, silvicultural practices—rather than direct control actions—more efficiently reduce root disease-related losses. Infected areas can be planted with less susceptible species of trees, for example, because some root disease fungi prefer specific tree species. The loss of suitable host tissue on the site eventually eliminates the fungus.

Reducing tree stress through silvicultural measures can alleviate some of the effects of root diseases. Stress can be caused by competition for light, moisture, and nutrients. And a root disease by itself can also cause stress by killing the roots, thus reducing the size of a tree's root system. Such stresses make a tree more susceptible to attacks by other pests, such as bark beetles. Reducing competition is best accomplished by maintaining only as much vegetation as a site can grow. Thinning and brush control are the methods most often used to reduce competition.

When competitive stresses are reduced, trees can tolerate root diseases, at least for a time, so that some productivity can be maintained in infected stands. However, reducing competition is not effective when the root disease can rapidly kill its host. Douglas-fir regeneration, for example, will be rapidly killed—regardless of stocking levels—in laminated root rot infection areas.

Direct suppression efforts are occasionally used. In the Southeast, where fruiting bodies of annosus root disease grow at the base of the tree, a low-intensity fire before thinning will reduce the amount of inoculum that remains to infect stumps. This same technique, however, is unsuccessful in the West, where most of the annosus fruiting bodies develop within stumps rather than in the duff. In the West, the high-intensity fire needed to kill the more protected fruiting bodies would damage or kill living trees.

For those root diseases that survive in stumps and root systems of dead trees, removing all host trees and leaving the site fallow for a prescribed time can be effective. A more aggressive and generally experimental approach attempts to remove infected tissue from the soil. This method is rarely used, because of the expense, the accompanying soil disturbance, and the difficulty in removing some root masses.

Outlook

The incidence of root diseases and the damage they cause will increase in managed forests. This increase will be related to increased use of forest stands, primarily more intensive timber management and additional recreational use.

As a result, the impact of root diseases on the various resources will be greater during the next 10 to 20 years. The degree of impact will partly depend on management. Some intensively managed forests that grow susceptible species could sustain considerable infection. In most situations, the increased incidence of root diseases will require changes in the way forests are managed so that losses are minimized.

In the next 10 to 20 years, we will learn more about root diseases. With this improved awareness will come the recognition that special management strategies may sometimes need to be implemented.

As we implement mitigating measures, root disease-related losses should stabilize and begin to decrease. Some of the measures, however, may require us to adjust our projected outputs. To be realistic, our future management plans will need to account for these adjustments and losses.

Literature Cited

The American Association of Nurserymen. 1981 directory of forest tree nurseries in the United States. [Place of publication unknown]; 1981. 40 p. In cooperation with: U.S. Department of Agriculture, Forest Service.

Amman, Gene D.; McGregor, Mark D.; Cahill, Donn B.; Klein, William H. Guidelines for reducing losses of lodgepole pine to the mountain pine beetle in unmanaged stands in the Rocky Mountains. Gen. Tech. Rep. INT–36. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 19 p.

Anderson, R.L.; Belanger, R.P.; Hoffard, W.H.; Mistretta, P.A.; Uhler, R.J. The integrated pest management decision key: a new decision-making tool for the forest manager. In: Microcomputers: a new tool for foresters: Proceedings of a conference cosponsored by the Society of American Foresters and Purdue University; 1982 May 18–20; West Lafayette, IN. SAF 82–05. Second printing Bethesda, MD: Society of American Foresters; 1983: 125–130.

Anderson, Robert L.; Hoffard, William H. Forest insect and disease conditions in the South, 1981. SA-FR. 16. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area; 1982. 54 p.

Anderson, Robert L.; Mistretta, Paul A. Management strategies for reducing losses caused by fusiform rust, annosus root rot, and littleleaf disease. Agric. Handb. 597. Washington, DC: U.S. Department of Agriculture; 1982. 30 p.

Borden, J.H.; Chong, L.J.; Pratt, K.E.G.; Gray, D.R. The application of behavior-modifying chemicals to contain infestations of the mountain pine beetle, *Dendroctonus ponderosae*. Forestry Chronicle. 1983 October: 235–239.

Boyer, J.N.; South, D.B. Forest nursery practices in the South. Southern Journal of Applied Forestry. 8(2): 67–75; 1984.

Brookes, Martha H.; Stark, R.W.; Campbell, Robert W., eds. The Douglas-fir tussock moth: a synthesis. Tech. Bull. 1585. Washington, DC: U.S. Department of Agriculture; 1978. 331 p.

Cole, W.E.; Cahill, D.B. Cutting strategies can reduce probabilities of mountain pine beetle epidemics in lodgepole pine. Journal of Forestry. 74(5): 294–297; 1976.

Cole, Walter E.; McGregor, Mark D. Estimating the rate and amount of tree loss from mountain pine beetle infestations. Res. Pap. INT–318. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 22 p.

Conn, J.E.; Borden, J.H.; Scott, B.E.; Friskie, L.M. Semiochemicals for the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae) in British Columbia; field trapping studies. Canadian Journal of Forest Research. 13(2): 320–324; 1983.

Cordell, Charles E. Nursery disease workshop introduction. In: Proceedings, Southern Nursery Conference; 1980 September 2–4; Lake Barkley, KY. Tech. Publ. SA–TP17. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area, State and Private Forestry; 1981: 108.

Daterman, G.E.; Livingston, R.L.; Wenz, J.M.; Sower, L.L. How to use pheromone traps to determine outbreak potential. Agric. Handb. 546. Washington, DC: U.S. Department of Agriculture; 1979. 11 p.

Dimond, J.B. Green Woods project: final report. Orono, ME: University of Maine, Maine Agricultural Experiment Station; 1984. 25 p.

Dinus, R.J.; Schmidt, R.A., eds. Management of fusiform rust in southern pines. In: Proceedings, 1976 fusiform rust symposium; 1976 December 7–8; Gainesville, FL. Gainesville, FL: University of Florida; 1977. 163 p.

Dull, C.W. Loran-C navigation systems as an aid to southern pine beetle surveys. Agric. Handb. 567; Washington, DC: U.S. Department of Agriculture, Forest Service; 1980. 15 p.

Edminster, Carleton B. RMYLD: Computation of yield tables for even-aged and two-storied stands. Res. Pap. RM–199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978. 26 p.

Hawksworth, F.G.: Mistletoes and their role in North America forestry. In: 2nd international symposium on parasitic weeds; 1979 July 16–19; Raleigh, NC. Raleigh, NC: North Carolina State University; 1979: 13–23.

Hawksworth, Frank G.; Wiens, Delbert. Biology and classification of dwarf mistletoes (*Arceuthobium*). Agric. Handb. 401. Washington, DC: U.S. Department of Agriculture; 1972. 234 p.

Hoffard, William H. Recent developments in management of insect pests of loblolly pine. In: Proceedings, 1982 symposium on the loblolly pine ecosystem (east region); 1982 December 8–10; Raleigh, NC. Raleigh, NC: North Carolina State University Press; 1982: 182–187.

Kettela, E.G. A cartographic history of spruce budworm defoliation 1967 to 1981 in Eastern North America. Info. Rep. DPC–X–14, Fredericton, NB: Environment Canada, Canadian Forestry Service, Maritimes Forest Research Center; 1983. 8 p.

Knight, Fred B. Managing forest pests—challenge of the 1980's. In: Hazard-rating systems in forest insect pest management: symposium proceedings; 1980 July 31–August 1; Athens, GA. Gen Tech. Rep. WO–27. Washington, DC: U.S. Department of Agriculture, Forest Service, 1981: 1–7.

Lightle, P.C.; Hawksworth, F.G. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest; Grand Canyon, Arizona. Res. Pap. RM–106. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1973. 22 p.

May, Jack T. Nursery soil management—a perspective. In: Proceedings, North American Forest Tree Nursery Soils Workshop; 1980 July 28–August 1; Syracuse, NY. Syracuse, NY: State University of New York; 1980: 300–310.

McGregor, Mark D.; Amman, Gene D.; Schmitz, Richard F.; Oakes, Robert D. Silviculture practices reduce losses of lodgepole pine to mountain pine beetles. Canadian Journal of Forest Research. [In press].

McManus, Michael L. The Gypsy Moth. For. Insect and Dis. Leafl. 162. Washington, DC: U.S. Department of Agriculture, Forest Service; 1980. 10 p.

Mitchell, Russell G.; Warring, Richard H.; Pitman, Gary B. Thinning lodgepole pine increases tree vigor and resistance to mountain pine beetle. Forest Science. 29(1): 204–211; 1983.

Phelps, W.R.; Czabator, F.L. Fusiform rust of southern pines. For. Insect and Dis. Leafl. 26. Washington, DC: U.S. Department of Agriculture, Forest Service; 1978. 8 p.

Powers, H.R.; Kraus, J.F.; Duncan, H.J. A seed orchard for resistant pines—progress and promise. Ga. For. Res. Rep. 1. Macon, GA: Georgia Forestry Commission; 1979. 8 p.

Powers, H.R., Jr.; McClure, J.P.; Knight, H.A.; Dutrow, G.F. Fusiform rust: Forest survey incidence data and financial impact in the South. Res. Pap. SE–127; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1975. 16 p.

Safranyik, L. Effects of weather and climate on mountain pine beetle populations. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: Proceedings of a symposium; 1978 April 25–27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 74–78.

Sower, L.L.; Daterman, G.E.; Funkhouser, W.; Sartwell, C. Pheromone disruption controls Douglas-fir tussock moth (Lepidoptera: Lymantriidae) reproduction at high insect density. Canadian Entomologist. 115(8): 965–969; 1983.

Thatcher, Robert C.; Searcy, Janet L.; Coster, Jack E.; Hertel, Gerard D., eds. The southern pine beetle. Tech. Bull. 1631. Washington, DC: U.S. Department of Agriculture; [1981]. 266 p.

Wickman, B.E.; Mason, R.R.; Thompson, C.G. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. Gen. Tech. Rep. PNW–5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 18 p.

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Appendix 2. Directory of Forest Pest Management Offices

Northern Region (R–1)

USDA Forest Service
Federal Building
Missoula, MT 59807

Rocky Mountain Region (R–2)

USDA Forest Service
P.O. Box 25127
Lakewood, CO 80225

Southwestern Region (R–3)

USDA Forest Service
Federal Building
517 Gold Avenue, S.W.
Albuquerque, NM 87102

Intermountain Region (R–4)

USDA Forest Service
Federal Building
324 25th Street
Ogden, UT 84401

Pacific Southwest Region (R–5)

USDA Forest Service
630 Sansome Street
San Francisco, CA 94111

Pacific Northwest Region (R–6)

USDA Forest Service
P.O. Box 3623
Portland, OR 97208

Southern Region (R–8)

USDA Forest Service
1720 Peachtree Rd., N.W.
Atlanta, GA 30367

Eastern Region (R–9) and Northeastern Area

USDA Forest Service
370 Reed Road
Broomall, PA 19008

Alaska Region (R–10)

USDA Forest Service
2221 E. Northern Lights Boulevard
Suite 104
Anchorage, AK 99504

Appendix 3. Common and Scientific Names of Pests

Common name	Scientific name
Douglas-fir tussock moth	*Orgyia pseudotsugata* (McD.)
Gypsy moth	*Lymantria dispar* L.
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins
Southern pine beetle	*Dendroctonus frontalis* (Zimm.)
Spruce budworm	*Choristoneura fumiferana* (Clemens)
Western spruce budworm	*Choristoneura occidentalis* Freeman
Dwarf mistletoes	*Arceuthobium* species
Fusiform rust	*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme*

The scientific names or causal agents of seed orchard pests, nursery pests, dwarf mistletoes, and root diseases are included in tables of corresponding chapters.

Appendix 4. Common and Scientific Names of Major Hosts

Common name	Scientific name
Alaska yellow cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
American basswood	*Tilia americana* L.
Apple	*Malus* spp.
Aspen	*Populus* spp.
Balsam fir	*Abies balsamea* (L.) Mill.
Black spruce	*Picea mariana* (Mill.) B.S.P.
Blue spruce	*Picea pungens* Engelm.
Corkbark fir	*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Eastern white pine	*Pinus strobus* L.
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Grand fir	*Abies grandis* (Doug. ex D. Don) Lindl.
Gray birch	*Betula populifolia* Marsh.
Hawthorn	*Crataegus* spp.
Limber pine	*Pinus flexilis* James
Loblolly pine	*Pinus taeda* L.
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Longleaf pine	*Pinus palustris* Mill.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Norway spruce	*Picea abies* (L.) Karst.
Oaks	*Quercus* spp.
Ohia	*Metrosideros collina* (Forst.) Gray
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes
Paper birch	*Betula papyrifera* Marsh.
Pines	*Pinus* spp.
Pond pine	*Pinus serotina* Michx.
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Red fir	*Abies magnifica* A. Murr.
Red spruce	*Picea rubens* Sarg.
Sand pine	*Pinus clausa* (Chapm.) Vasey
Scotch pine	*Pinus sylvestris* L.
Shortleaf pine	*Pinus echinata* Mill.
Slash pine	*Pinus elliottii* Engelm. var.*elliottii*
Spruces	*Picea* spp.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Sugar pine	*Pinus lambertiana* Dougl.
Sweetgum	*Liquidambar styraciflua* L.
Tamarack	*Larix laricina* (Du Roi) K. Koch
True firs	*Abies* spp.
Virginia pine	*Pinus virginiana* Mill.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western larch	*Larix occidentalis* Nutt.
Western redcedar	*Thuja plicata* Donn
Western white pine	*Pinus monticola* Dougl. ex D. Don
White fir	*Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr.
White spruce	*Picea glauca* (Moench) Voss
Whitebark pine	*Pinus albicaulis* Engelm.
Willow	*Salix* spp.

This publication reports the use of pesticides and research with pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

The mention of products and companies by name does not constitute endorsement by the U.S. Department of Agriculture, nor does it imply approval of a product to the exclusion of others that may also be suitable.